Computed Fluxes at the CERES Footprint Level: Reintroducing the CERES Level 2 Cloud Radiative Swath (CRS) Product

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Background

- CERES instruments sample radiation at TOA - not at the Earth's surface or in the atmosphere
  - The standard Level 2 SSF provides CERES TOA fluxes & parameterized surface fluxes at the footprint scale
  - For most of CERES, footprint-level surface fluxes have been estimated using SOFA algorithms

- CRS builds on the standard CERES L2 SSF product to provide a comprehensive suite of instantaneous footprint-level irradiances calculated using a fast, correlated-k radiative transfer code – the NASA Langley Fu-Liou Radiative Transfer model
  - CRS was initially developed & publicly released in the 2000s (Ed 2); production ceased in the late 2000s due to greater emphasis on Level 3 products and limited computational resources at the time
  - Over the past 9 months, efforts have been underway to resurrect & modernize the CRS code

- We seek to enhance CERES L2 product offerings while improving the accuracy of footprint-level surface fluxes. Here, we reintroduce CRS & show preliminary assessments of its performance:

  0. How CRS extends and improves the standard CERES SSF
  1. Evaluating CRS outgoing TOA LW and SW fluxes against CERES observations
  2. Comparisons of instantaneous CRS1deg$_{\beta}$ and SYN1deg-Hour L3 fluxes (TOA, surface)
  3. How do CRS surface fluxes compare to those from SOFA algorithms ("Model B")?
  4. Validation of CRS downwelling surface fluxes against measurements across the globe

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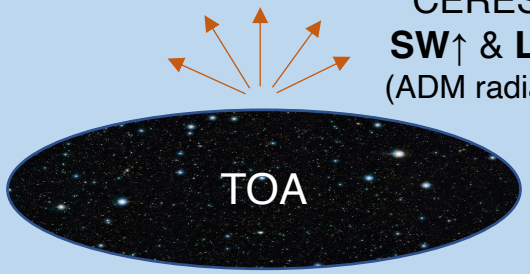
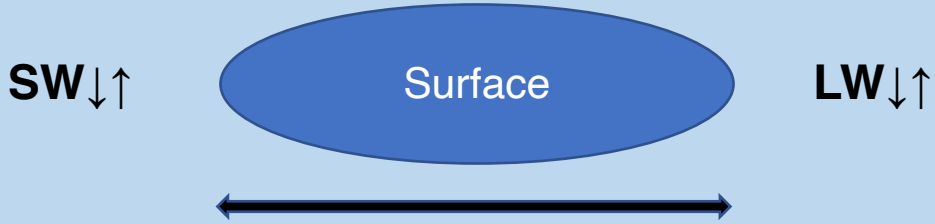
CERES SSF



CERES derived
SW↑ & **LW↑** fluxes
(ADM radiance to flux)

Parameterized Surface Broadband Fluxes:
e.g., “Model B”
Langley Parameterized Longwave Algorithm
Langley Parameterized Shortwave Algorithm



CERES Footprint / FOV
Terra, Aqua, NPP, NOAA-20

CERES CRS

Inputs

CERES SSF Ed4A
geolocated FOVs, etc.

GEOS 5.4.1
$T(z)$, $p(z)$, $q(z)$, $O_3(z)$
surface wind speed

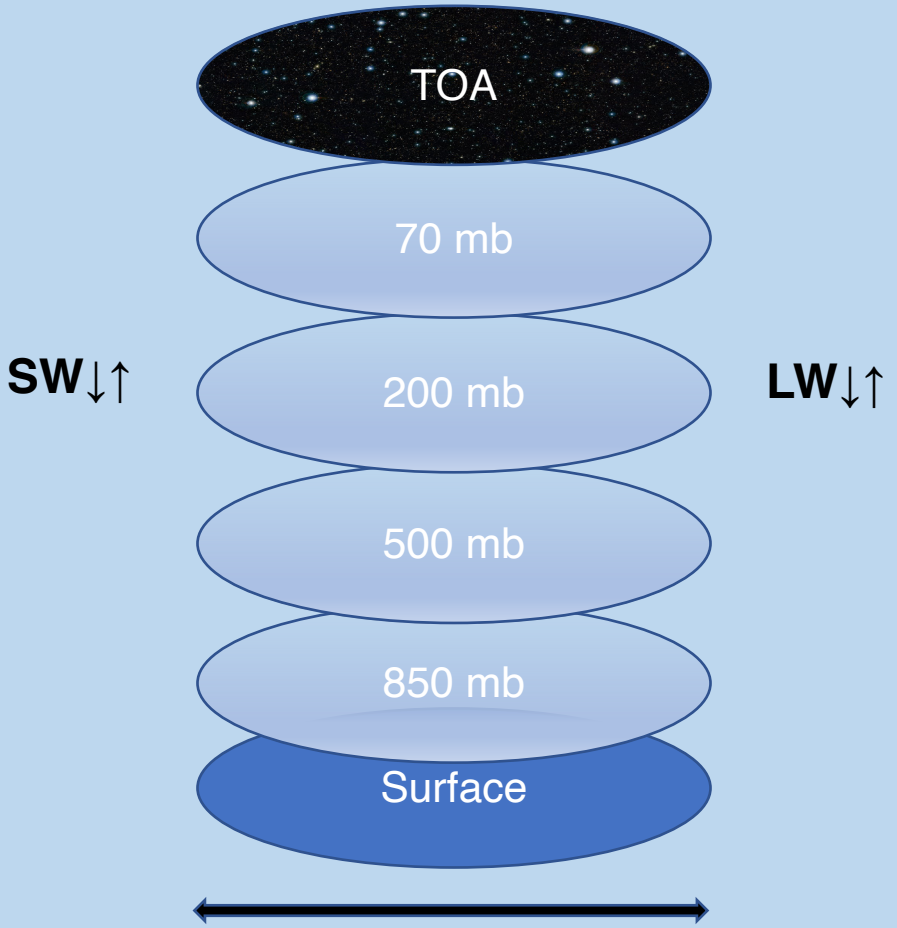
MODIS
cloud properties (Ed4)
spectral albedo
land temp (clear)
AOD (sometimes)

MATCH hourly
aerosol profiles & AOD

IGBP surface type

surface albedo history
map (cloudy)

Langley Fu-Liou
Radiative Transfer Model



CERES Footprint / FOV
Terra FM1, Aqua FM3

Outputs

instantaneous vertical
profiles (6 levels) of
broadband fluxes +
spectrally-resolved fluxes
at the surface and TOA

4-stream SW
2-stream LW

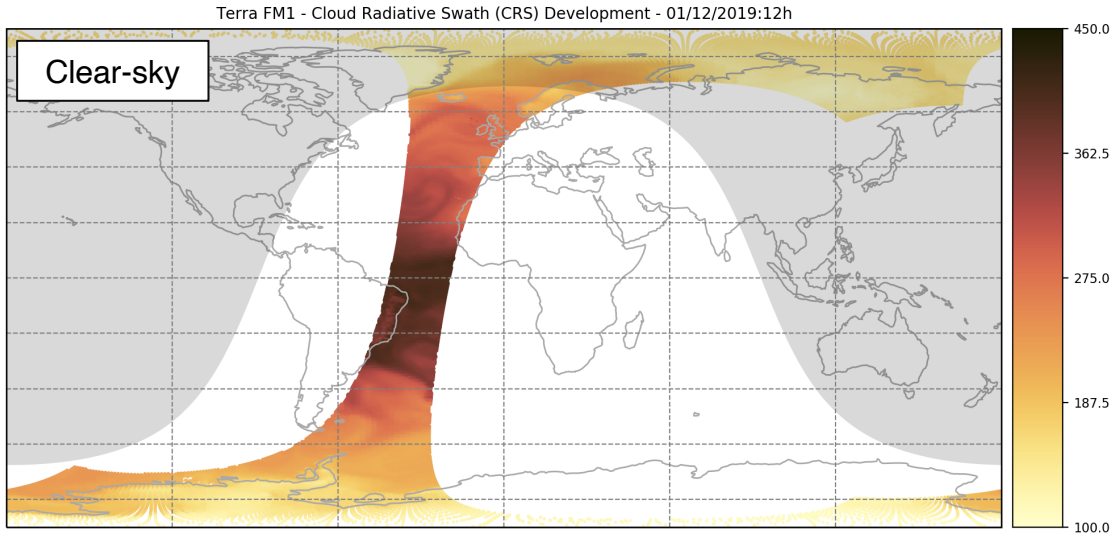
LW : 12 bands
SW : 14 bands

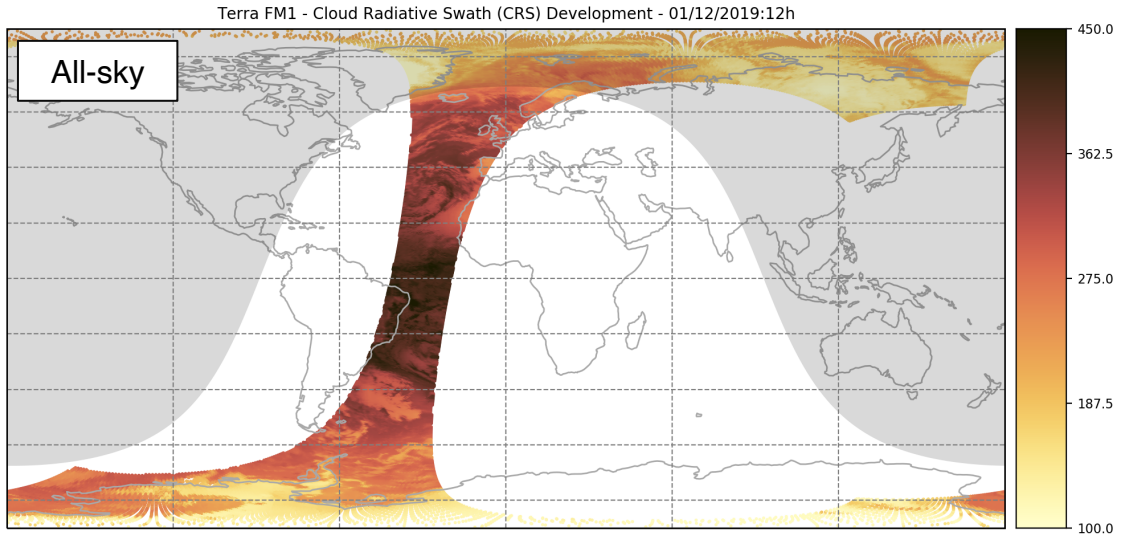
(surface, all-sky)
SW direct + diffuse
PAR, UV fluxes

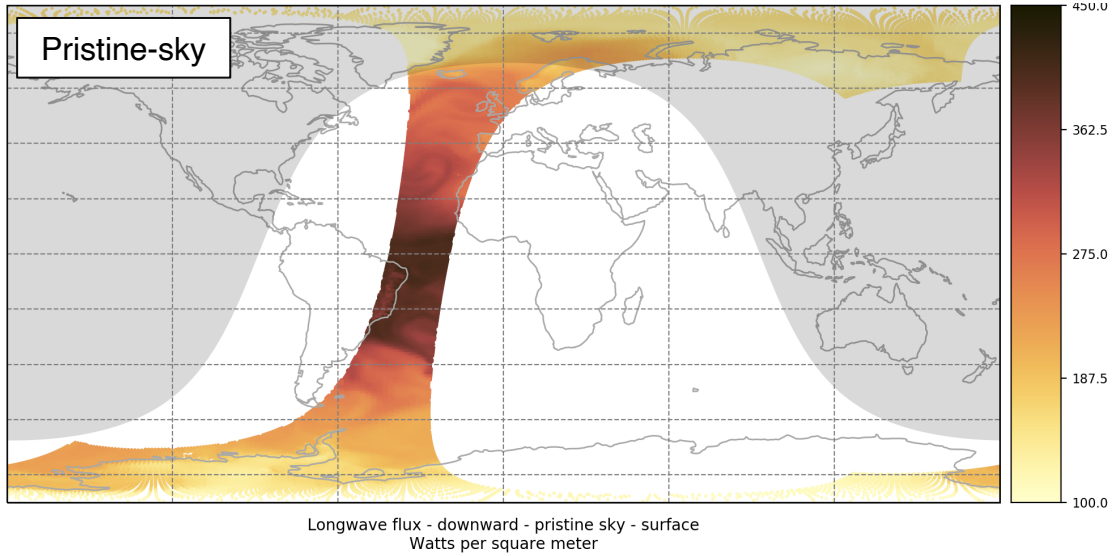
~ 2,300,000 FOV
calculations / day

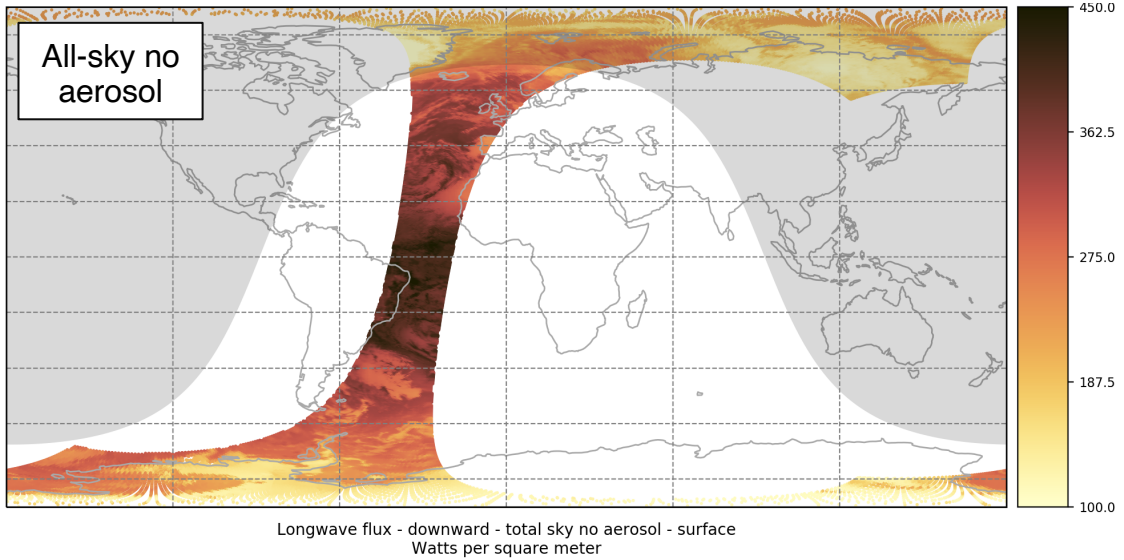
No longer tuning to
the CERES TOA flux
(as in Ed 2)

CRS Computed Fluxes – Broadband Surface LW↓ Flux









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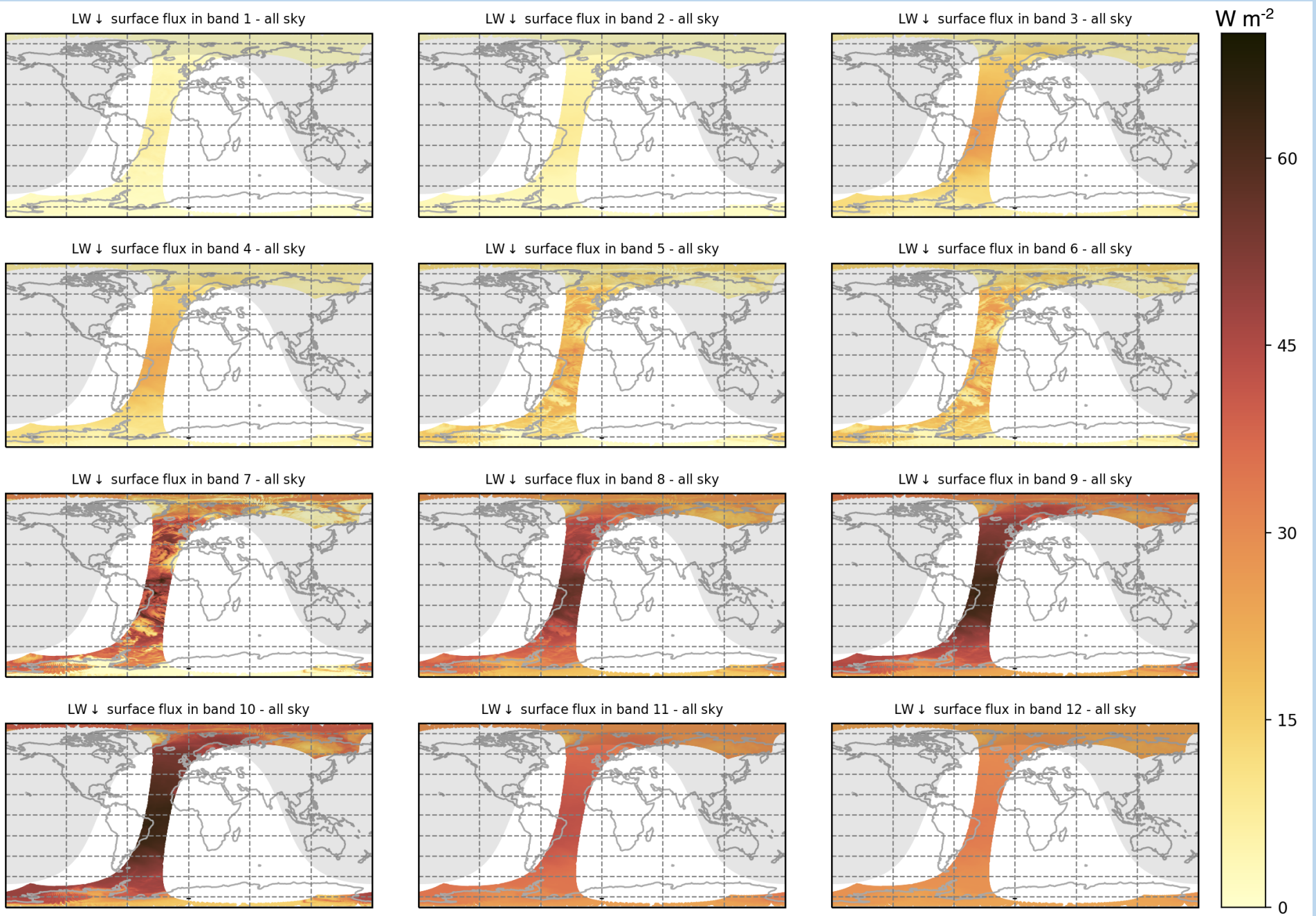
CRS Computed Fluxes

Narrowband
Surface
LW↓ Fluxes
All-Sky

LW Bands

1: 2200 - 1900 cm^{-1}
2: 1900 - 1700 cm^{-1}
3: 1700 - 1400 cm^{-1}
4: 1400 - 1250 cm^{-1}
5: 1250 - 1100 cm^{-1}
6: 1100 - 980 cm^{-1}
7: 980 - 800 cm^{-1}
8: 800 - 670 cm^{-1}
9: 670 - 540 cm^{-1}
10: 540 - 400 cm^{-1}
11: 400 - 280 cm^{-1}
12: 280 - 0 cm^{-1}

IR window ~ bands 5 - 7



0. How CRS extends / improves the standard SSF

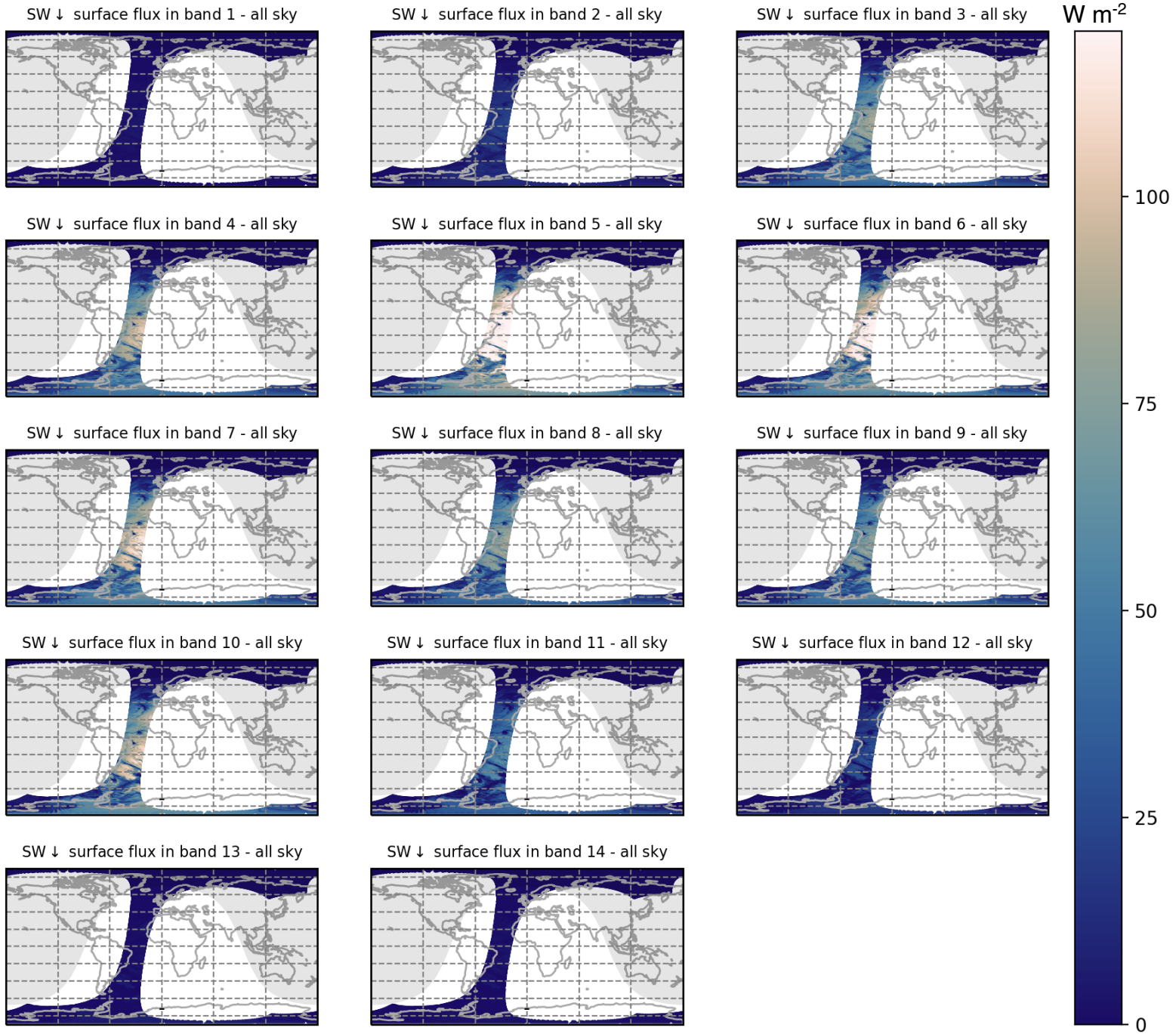
CRS Computed Fluxes

Narrowband
Surface
SW↓ Fluxes
All-Sky

SW Bands

1: 0.1754 - 0.3225 μm
2: 0.3225 - 0.3575 μm
3: 0.3575 - 0.4375 μm
4: 0.4375 - 0.4975 μm
5: 0.4975 - 0.5950 μm
6: 0.5950 - 0.6896 μm
7: 0.6896 - 0.7940 μm
8: 0.7940 - 0.8890 μm
9: 0.8990 - 1.0420 μm
10: 1.0420 - 1.4100 μm
11: 1.4100 - 1.9048 μm
12: 1.9048 - 2.5000 μm
13: 2.5000 - 3.5088 μm
14: 3.5088 - 4.0000 μm

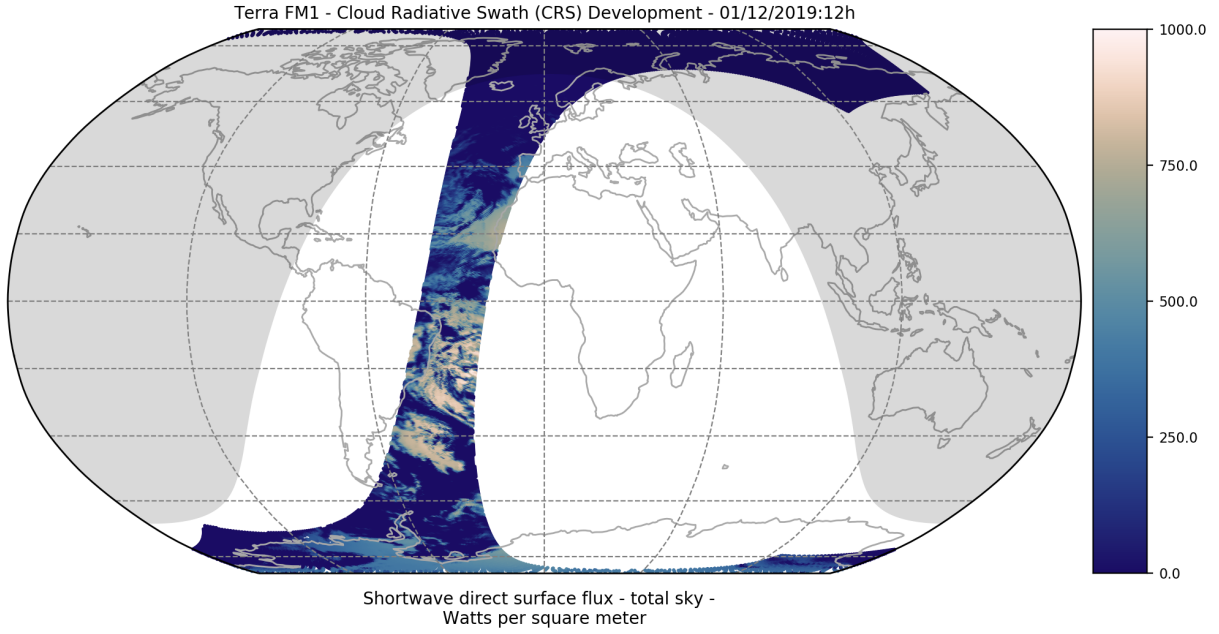
PAR ~ bands 4 - 6



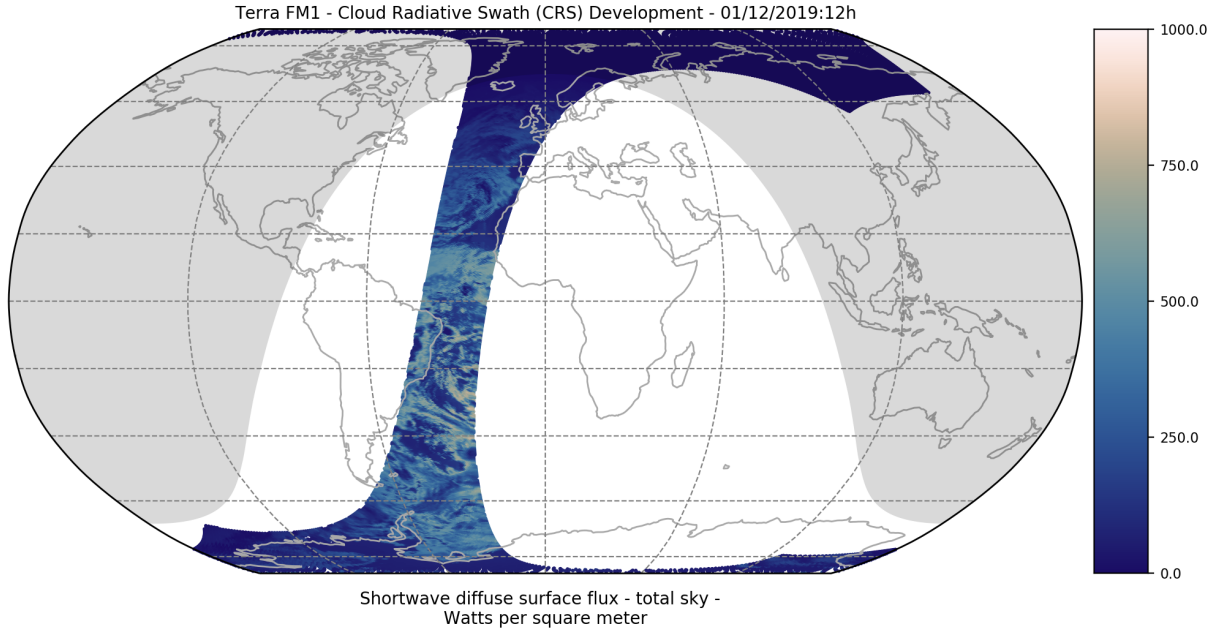
0. How CRS extends / improves the standard SSF

CRS Computed Fluxes
Surface SW↓ Flux Components

Direct SW Radiation



Diffuse SW Radiation



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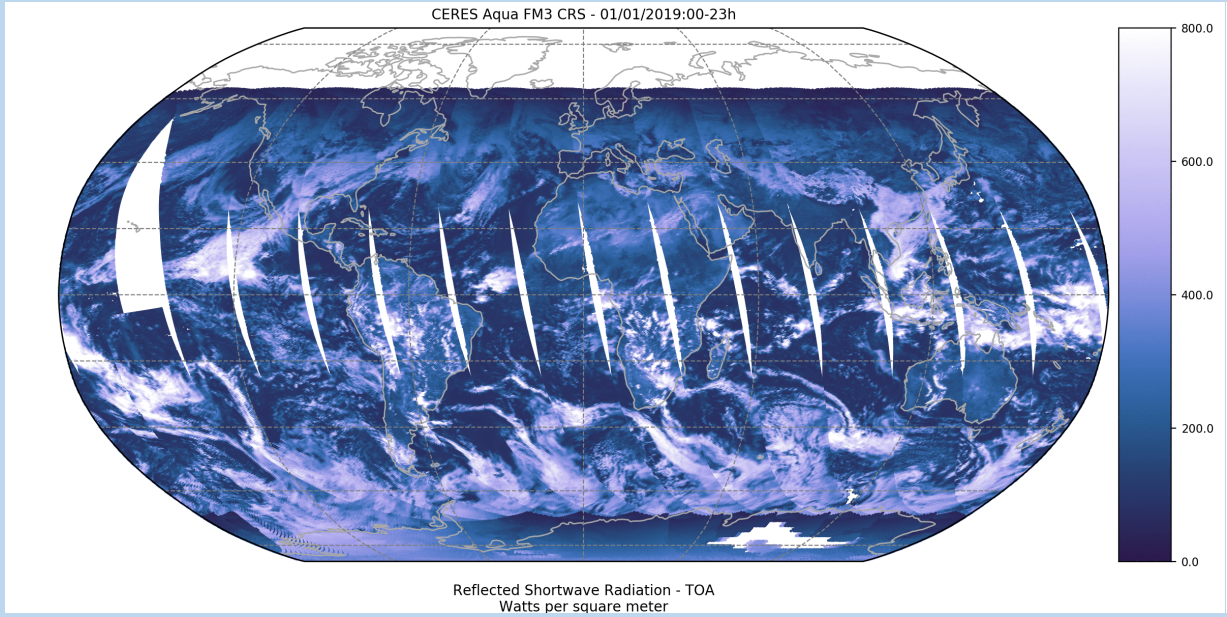
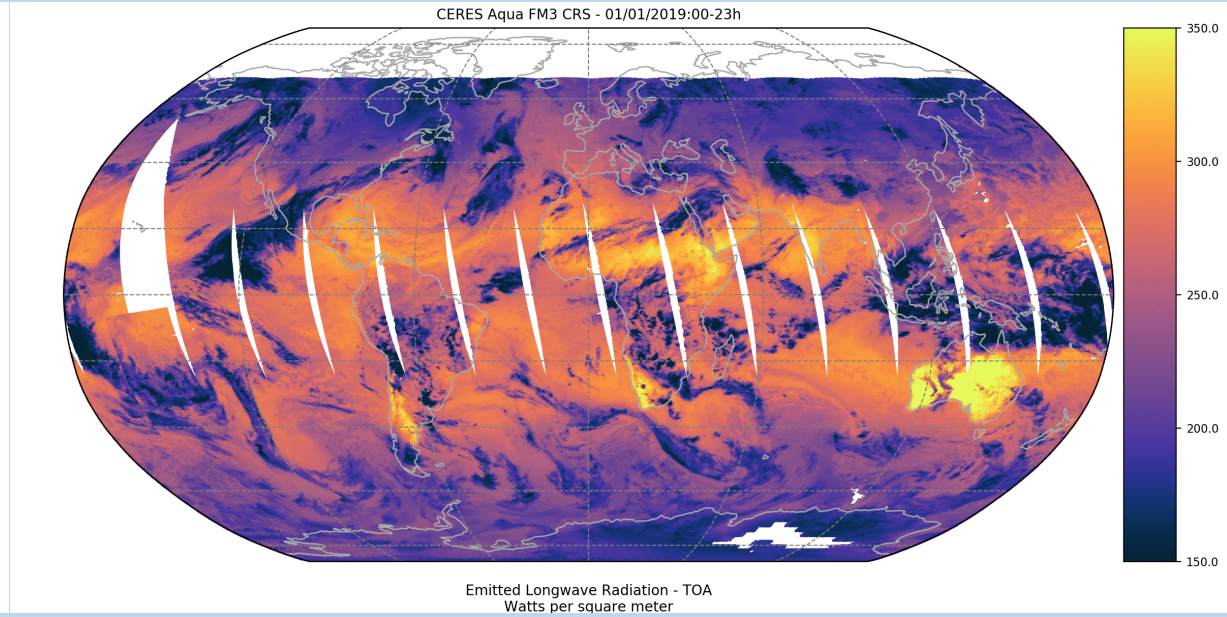
CRS Computed Fluxes
Top-of-Atmosphere

Reflected SW Radiation



Outgoing LW Radiation



How does CRS compare to CERES observations?

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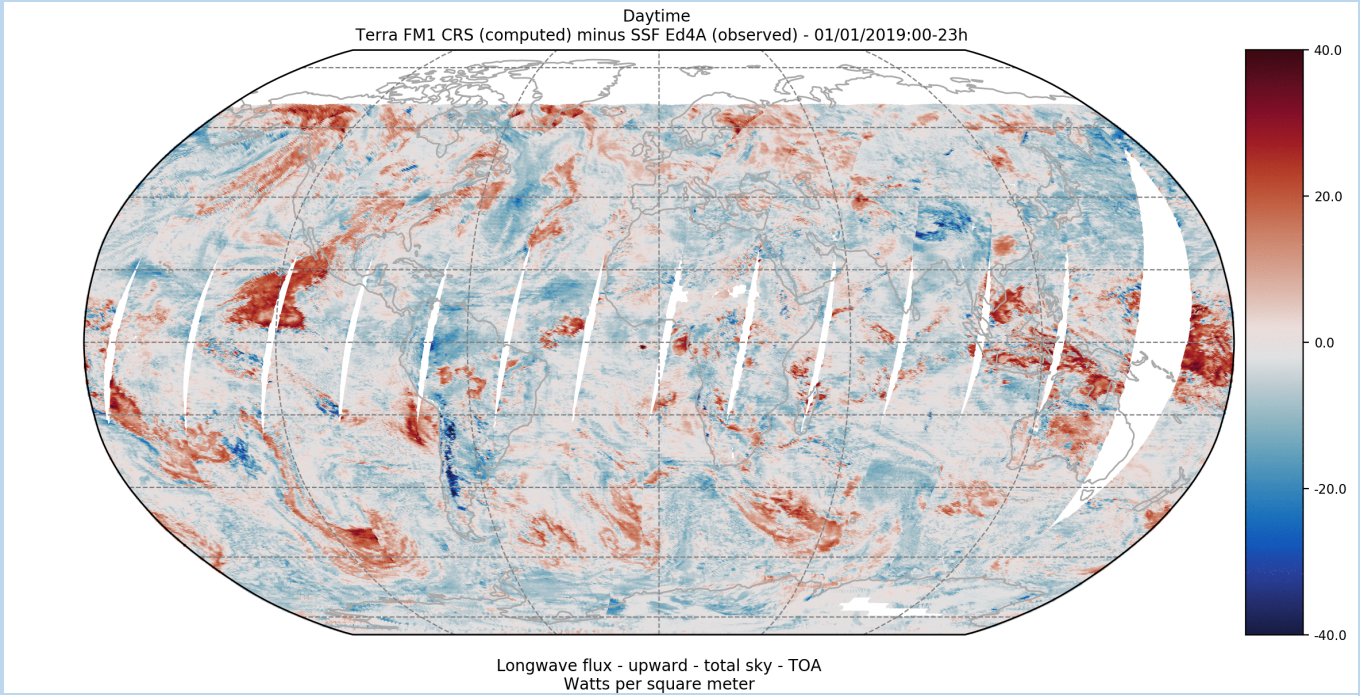
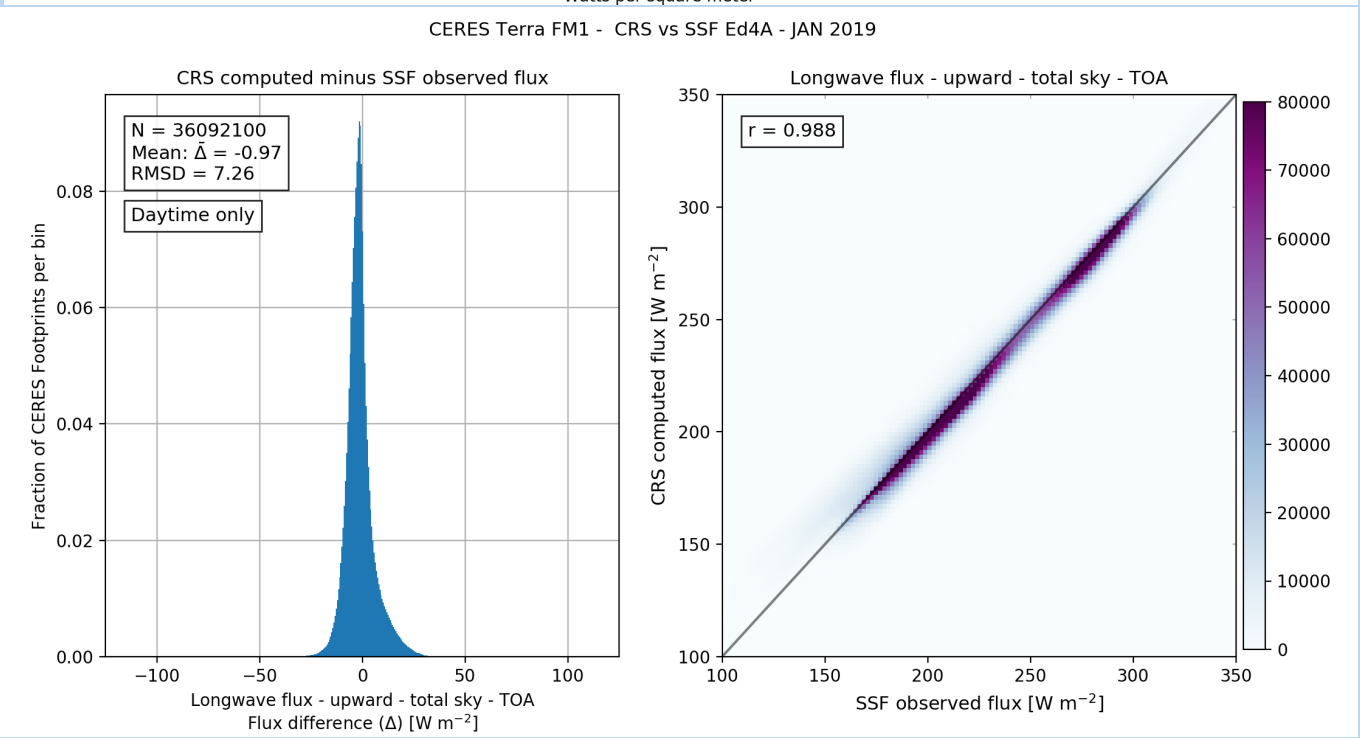
Evaluating CRS Fluxes Against CERES TOA Observations (SSF Ed4A)

- Scene-dependent bias: excessive OLR from thick, high cloud systems
- Insufficient OLR from many other scenes
  - GEOS 5.4.1 $T(z)$, $q(z)$ bias?
- +OLR bias mitigated by standard cloud retrievals (here) vs multi-layer / overlap cloud retrievals
- Nevertheless, decent global-scale monthly agreement
- Global monthly statistics (area-weighted)
  - Mean Δ = -0.97 W m^{-2}
  - RMSD = 7.26 W m^{-2}
  - Correlation r = 0.99



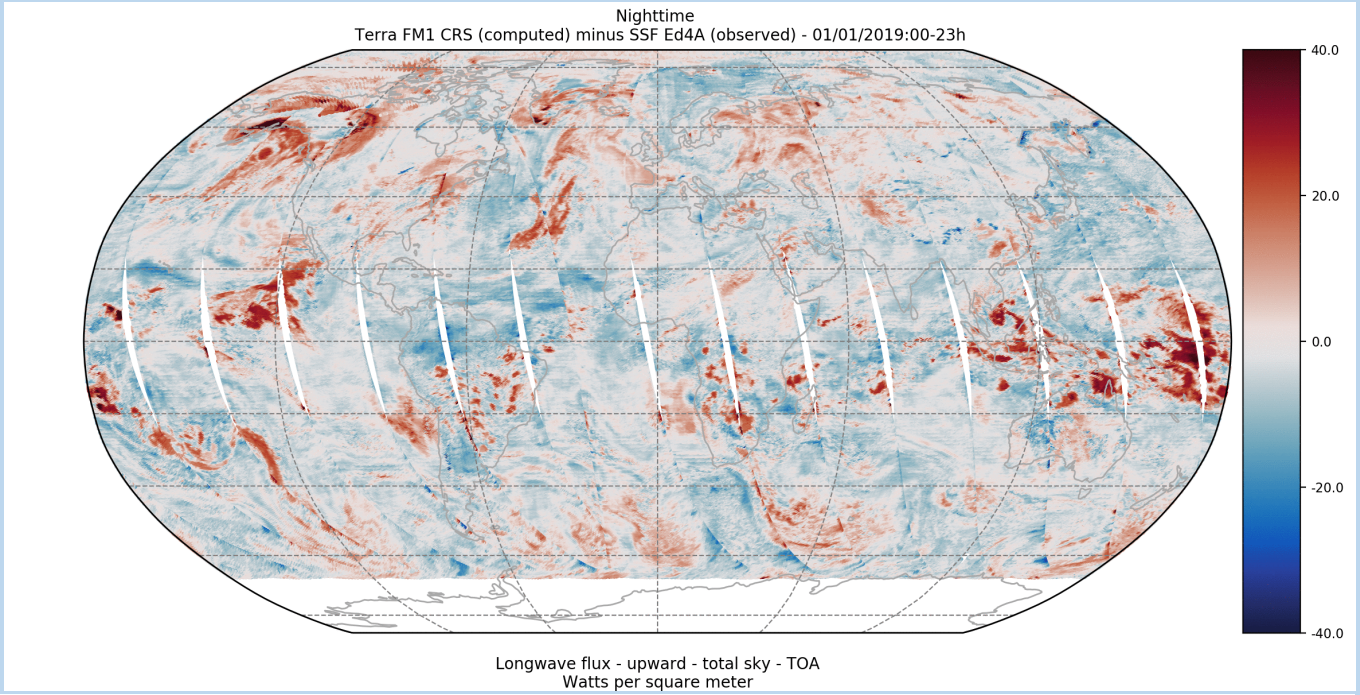
LW↑ bias (Δ) daily geographic variability



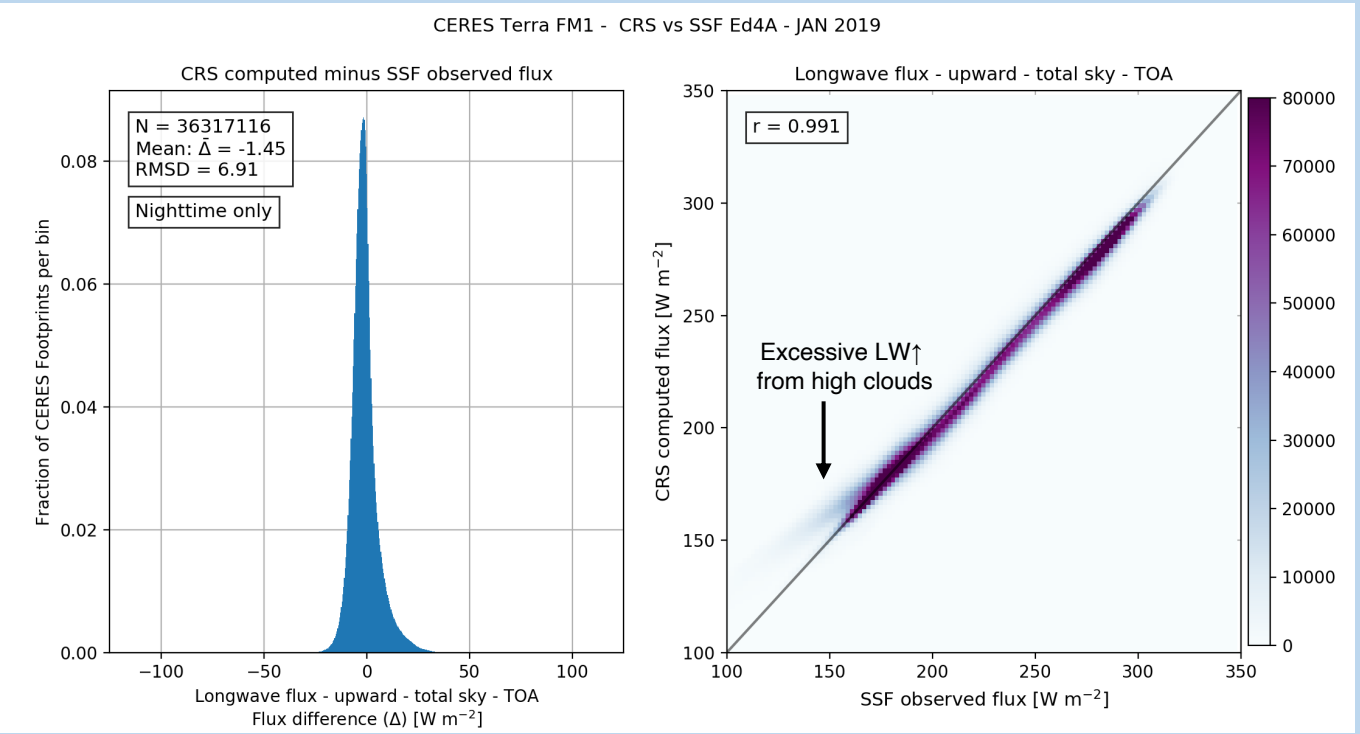
Monthly statistics JAN 2019

Evaluating CRS Fluxes Against CERES TOA Observations (SSF Ed4A)

- Scene-dependent bias: excessive OLR from thick, high cloud systems
- Insufficient OLR from many other scenes
  - GEOS 5.4.1 $T(z)$, $q(z)$ bias?
- Largest nighttime +OLR errors typically attributed to Indo-Pacific warm pool deep convection
- Nevertheless, decent global-scale monthly agreement
- Global monthly statistics (area-weighted)
  - Mean Δ = -1.45 W m^{-2}
  - RMSD = 6.91 W m^{-2}
  - Correlation r = 0.99



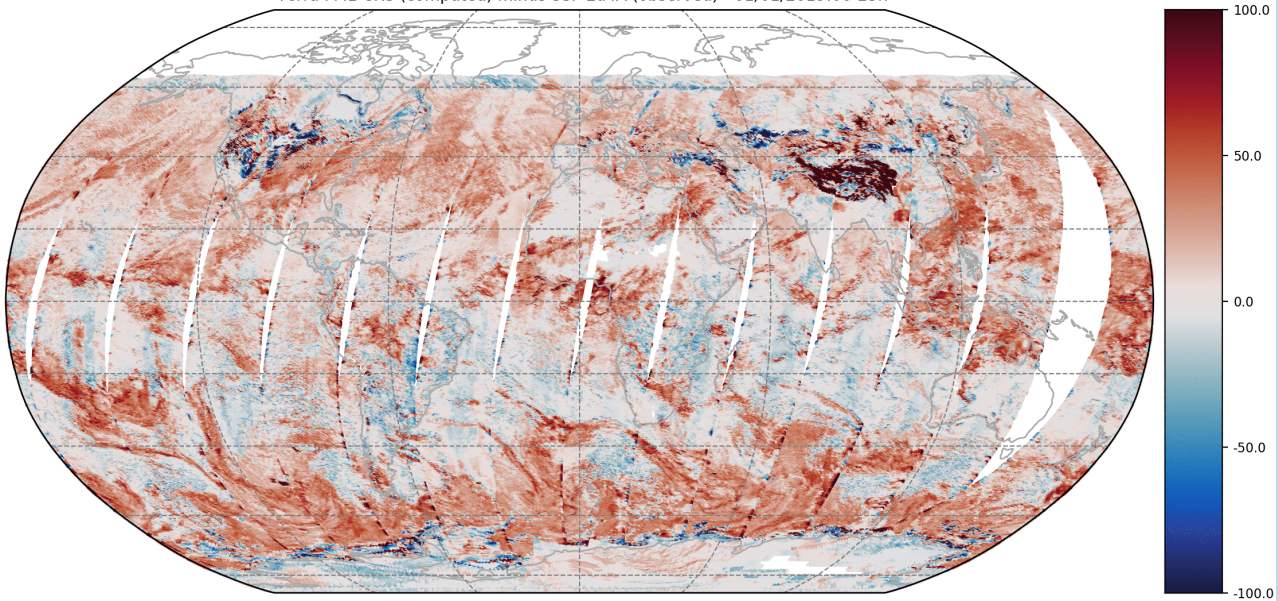
LW↑ bias (Δ) nightly geographic variability



Monthly statistics JAN 2019

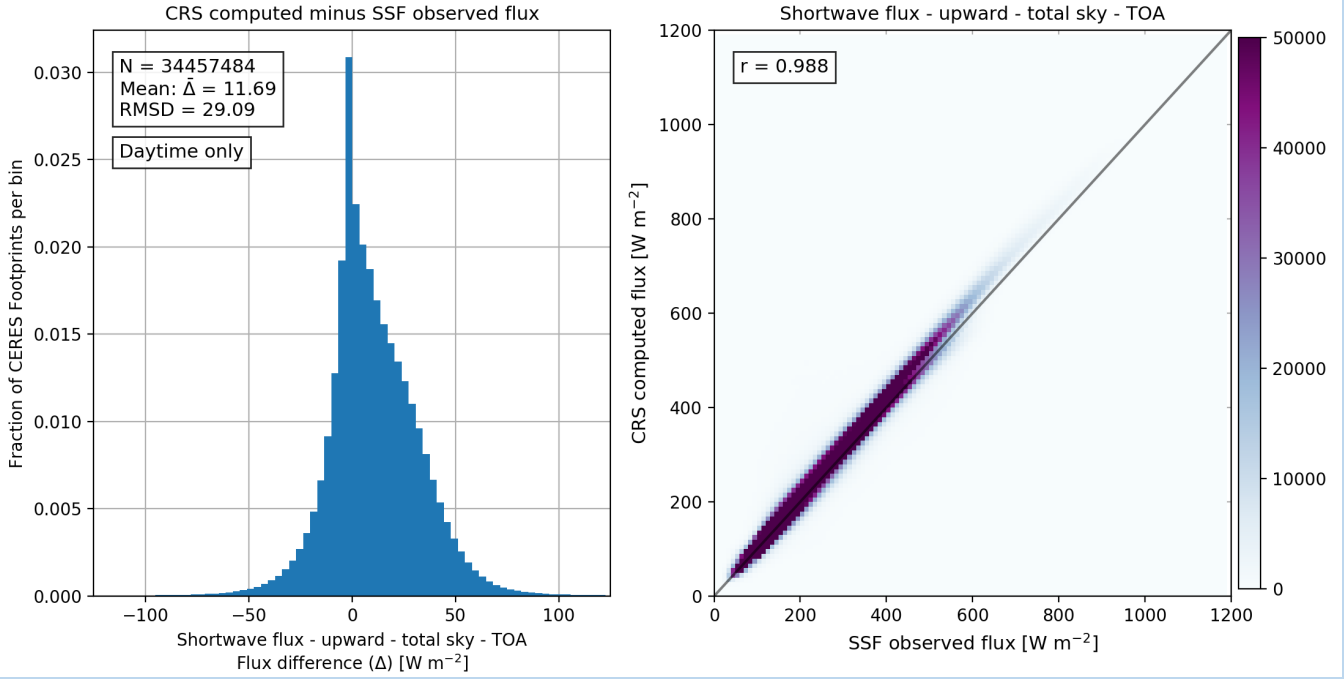
Evaluating CRS Fluxes Against CERES TOA Observations (SSF Ed4A)

- Excessive SW reflection to space relative to CERES
- Cloud reflection errors may, in part, be attributed to cloud fraction and/or optical depth retrievals
  - e.g., partly cloudy pixels (Ham et al. 2019)
  - issue persists since Ed2G
- CRS surface albedo retrieval issues evident over NH continental regions
  - Tibetan Plateau, Rockies and surrounding regions
- Global monthly statistics (area-weighted)
  - Mean Δ = 11.69 W m^{-2}
  - RMSD = 29.09 W m^{-2}
  - Correlation = 0.99



SW↑ bias (Δ) daily geographic variability ←

CERES Terra FM1 - CRS vs SSF Ed4A - JAN 2019

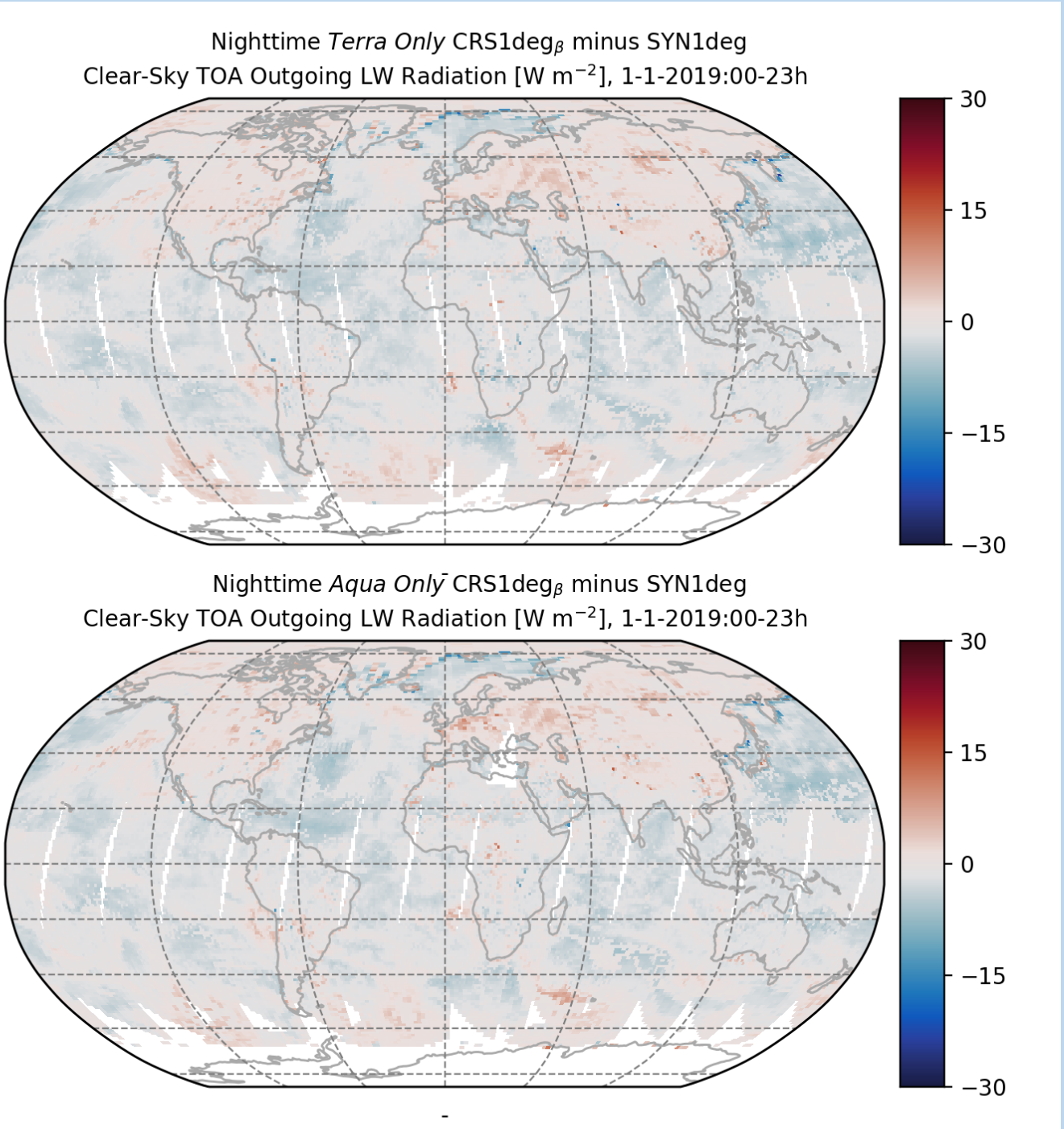


Monthly statistics JAN 2019 ←

1. Evaluating CRS against CERES observations

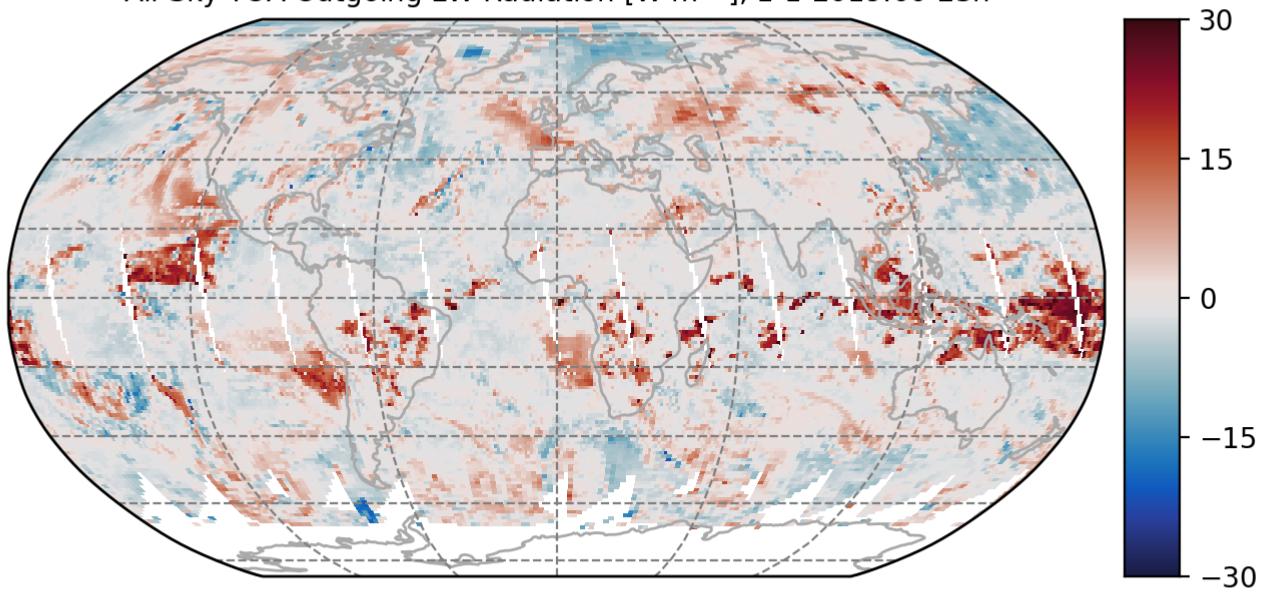
Comparing CRS1deg$_\beta$ and SYN1deg-Hour Ed4A Instantaneous TOA LW Fluxes

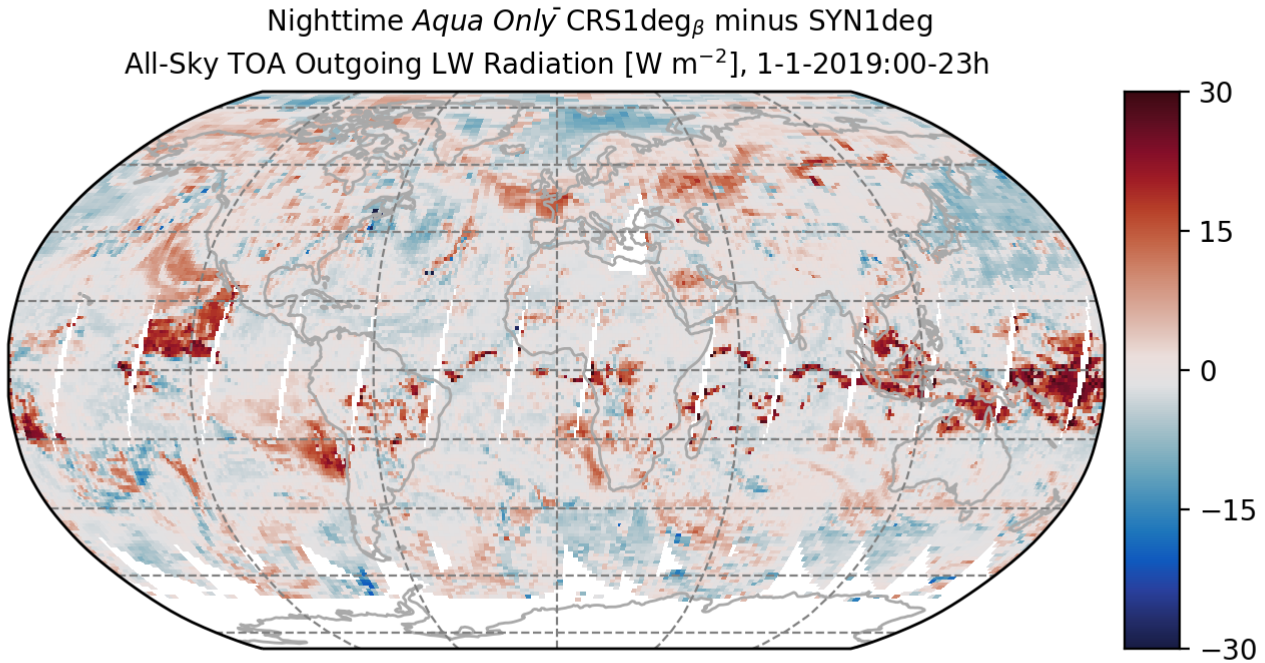
- CERES SARB/TISA groups perform similar calculations in SYN1deg-Hour
  - Level 3 gridded hourly product
  - Fu-Liou RT model computed fluxes
  - Has been more rigorously developed and validated
- We also evaluate CRS fluxes against SYN1deg calculations
  1. Average CRS FOVs to 1°x1° CERES nested grid to produce gridded "CRS1deg$_\beta$-Hour" product
  2. Isolate grid boxes observed by Terra or Aqua only (no GEO) & evaluate instantaneous flux Δ
- Understanding differences in fluxes & algorithms can help further diagnose issues
- Relatively good clear-sky OLR agreement between CRS1deg$_\beta$ and SYN1deg →



Comparing CRS1deg$_\beta$ and SYN1deg-Hour Ed4A Instantaneous TOA LW Fluxes

- CERES SARB/TISA groups perform similar calculations in SYN1deg-Hour
  - Level 3 gridded hourly product
  - Fu-Liou RT model computed fluxes
  - Has been more rigorously developed and validated
- We also evaluate CRS fluxes against SYN1deg calculations
  1. Average CRS FOVs to 1°x1° CERES nested grid to produce gridded "CRS1deg$_\beta$-Hour" product
  2. Isolate grid boxes observed by Terra or Aqua only (no GEO) & evaluate instantaneous flux Δ
- CRS high/thick clouds warmer/emissive relative to SYN1deg, like CERES observations
- Large ΔOLR over subtropical stratocumulus decks
  - Californian, Peruvian, Namibian





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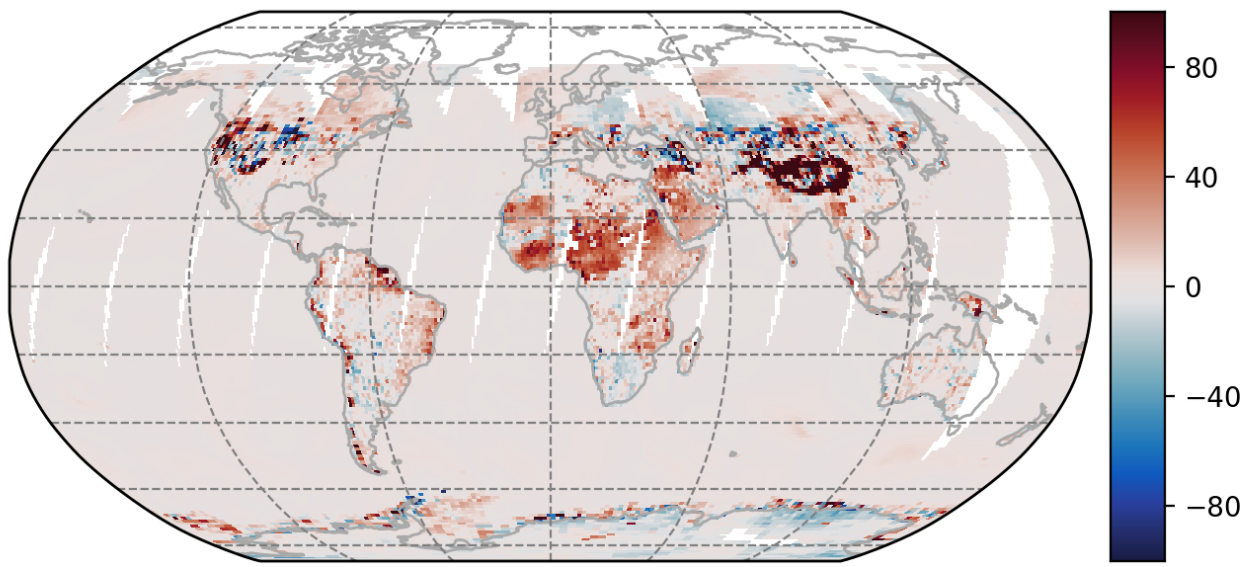
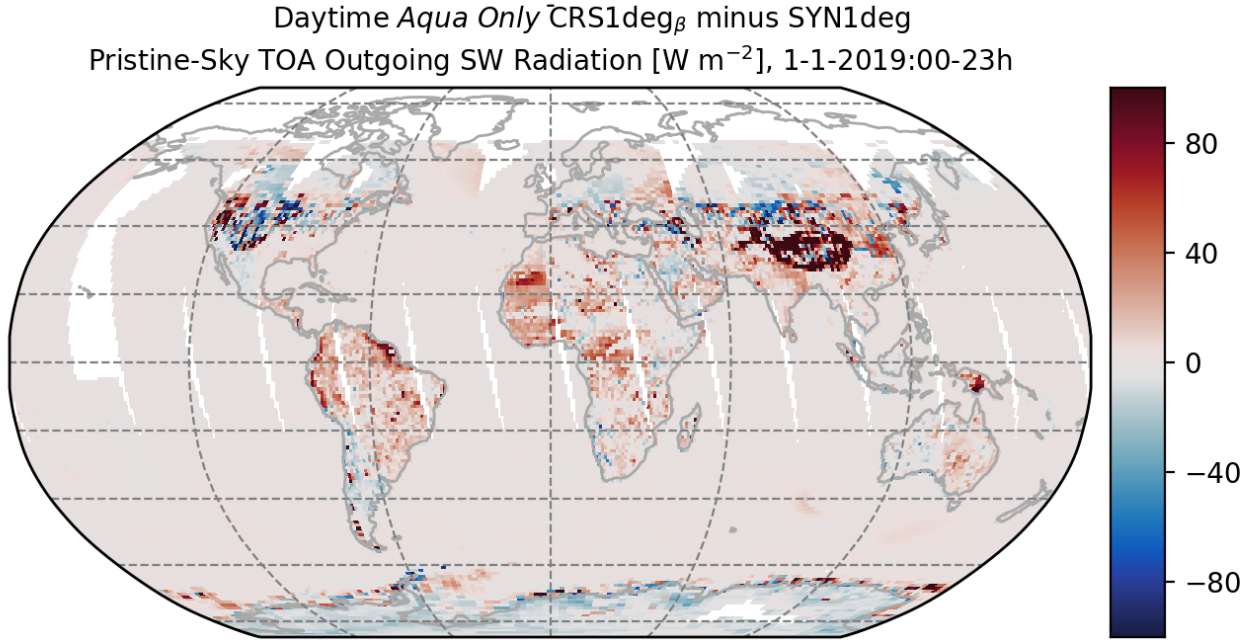
Comparing CRS1deg$_\beta$ and SYN1deg-Hour Ed4A Instantaneous TOA SW Fluxes

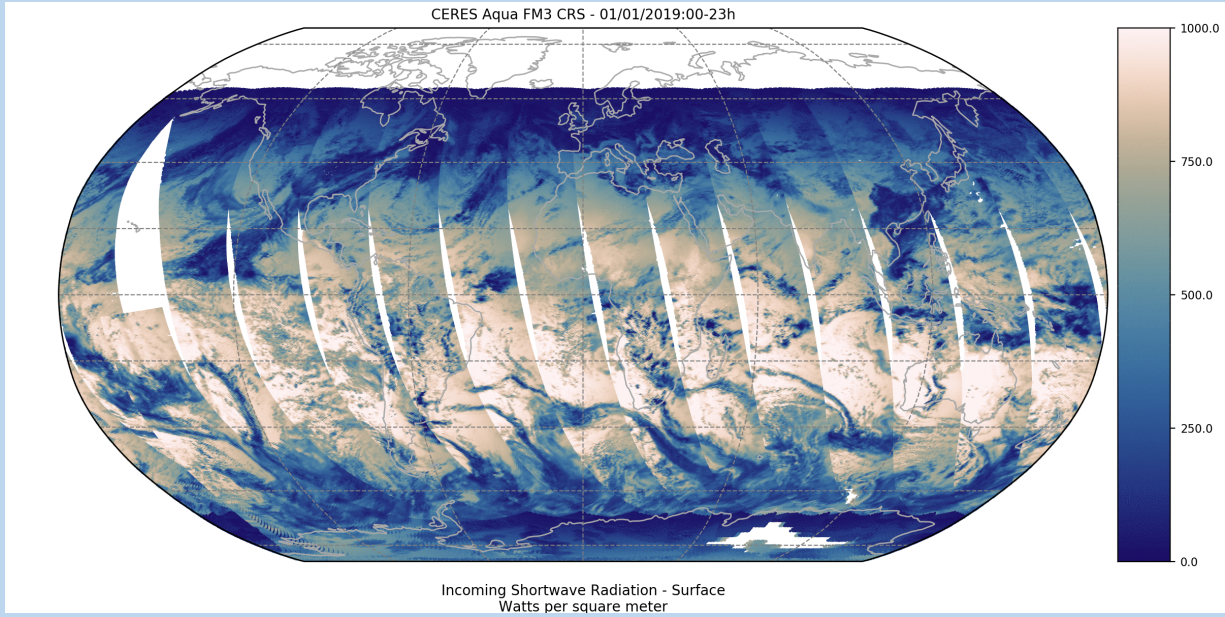
- CERES SARB/TISA groups perform similar calculations in SYN1deg-Hour
  - Level 3 gridded hourly product
  - Fu-Liou RT model computed fluxes
  - Has been more rigorously developed and validated
- We also evaluate CRS fluxes against SYN1deg calculations
  1. Average CRS FOVs to 1°x1° CERES nested grid to produce gridded "CRS1deg$_\beta$-Hour" product
  2. Isolate grid boxes observed by Terra or Aqua only (no GEO) & evaluate instantaneous flux Δ
- Pristine ΔSW ~ 0 over ocean
  - Similar algorithms
- Large ΔSW over land highlight CRS surface albedo retrieval
  - CRS retrieval relies on tuning algorithm, SZA, PWV, AOD
  - Working to understand differences



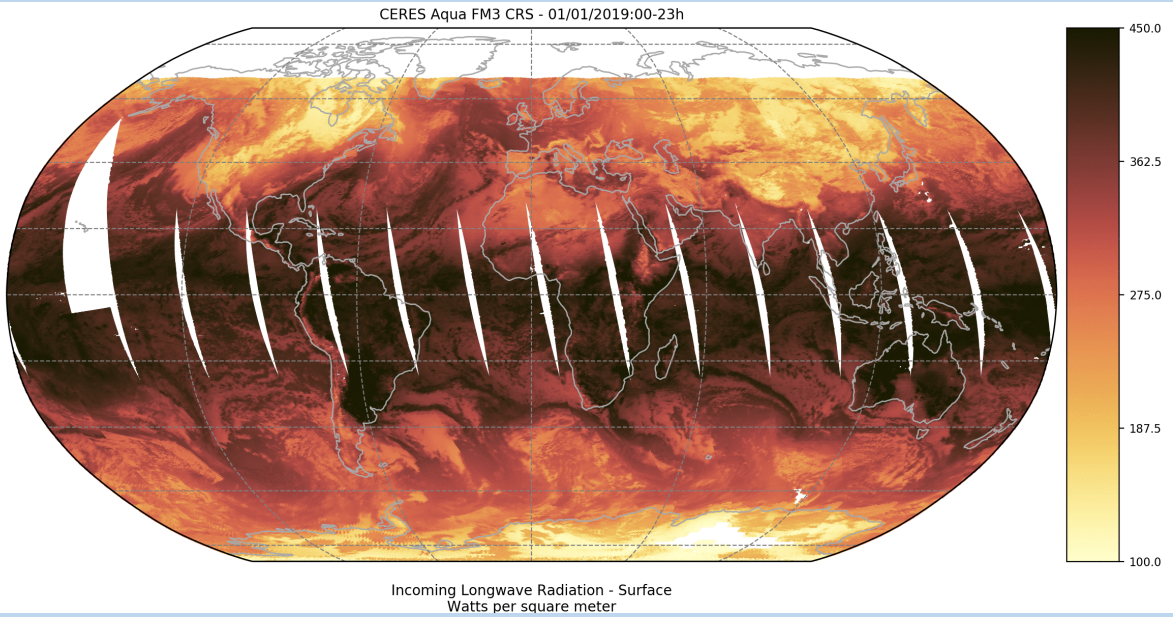


CRS Computed Fluxes
Surface Downwelling Radiation

Surface SW↓ Irradiance



Surface LW↓ Irradiance



How does CRS compare to SSF Model B and ground-based radiation measurements?

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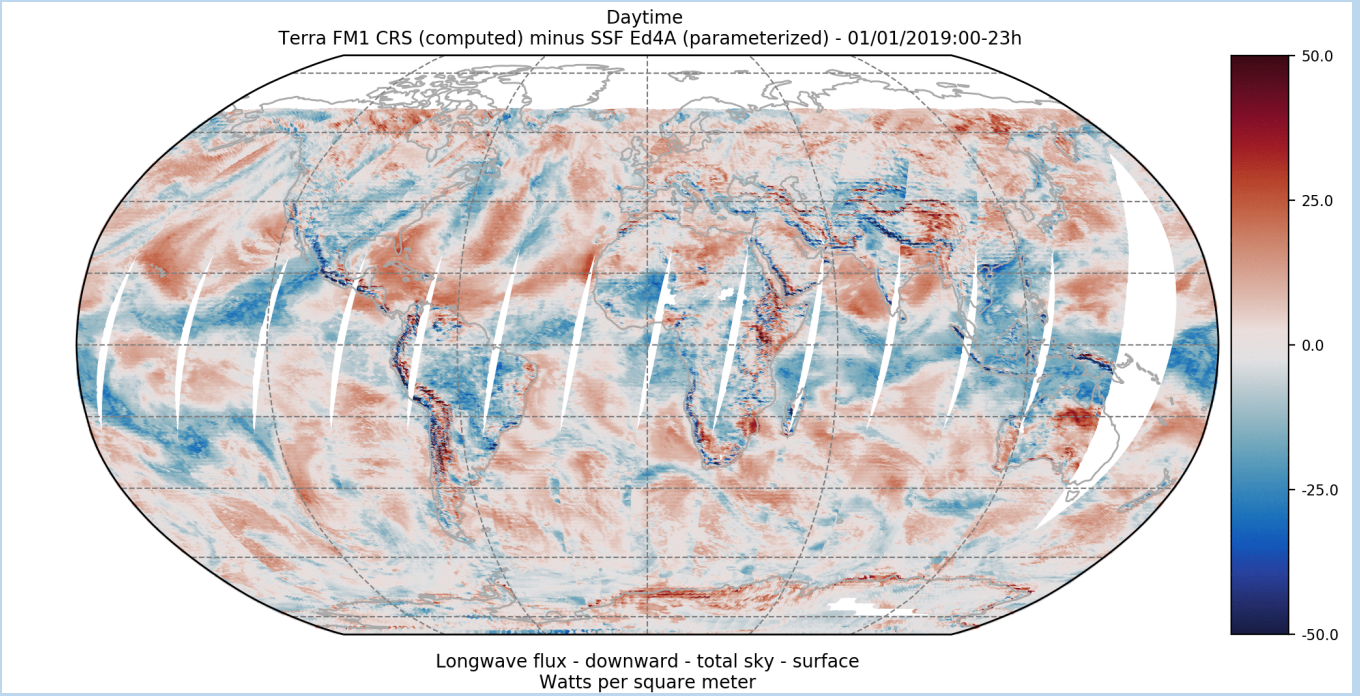
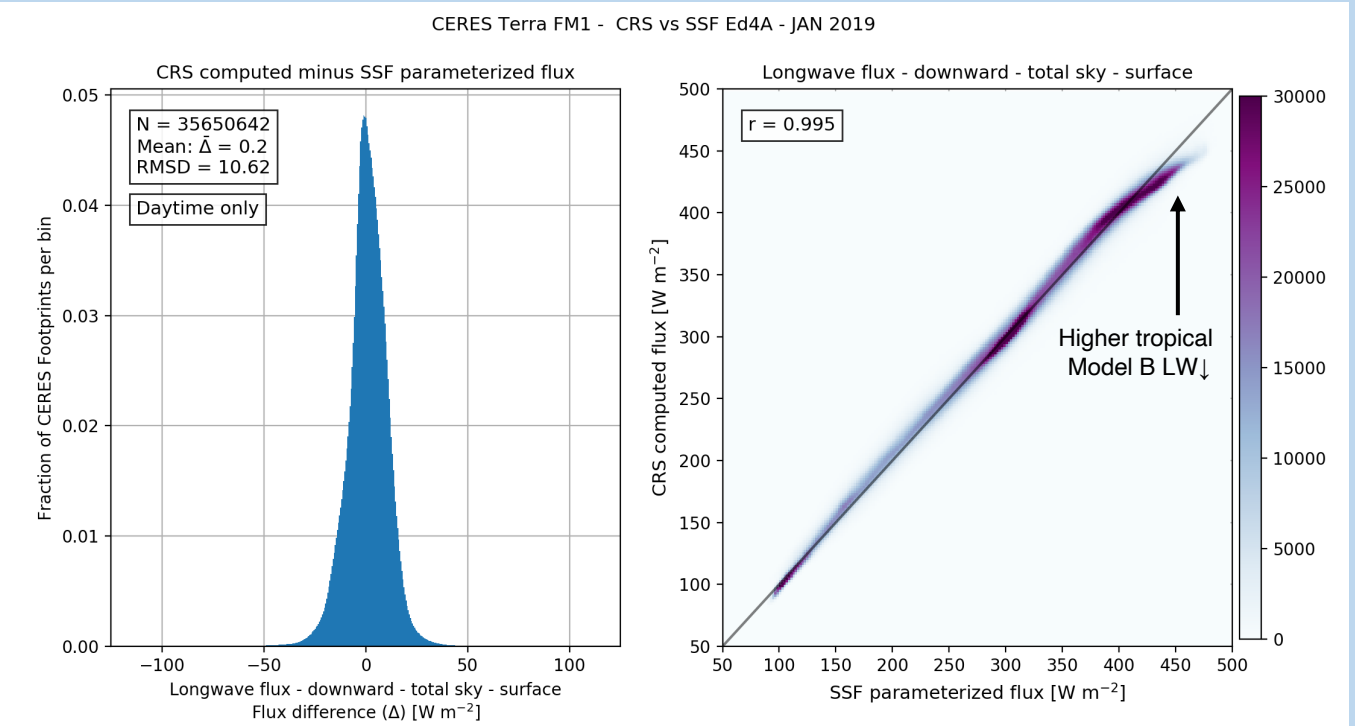
Comparing CRS and "Model B" Parameterized Surface Fluxes (SSF Ed4A)

- CRS LW↓ fluxes are slightly larger than those estimated by Model B, on average
- CRS LW↓ lower in tropical areas with vertically extensive cloud systems / high precipitable water
  - ITCZ, SPCZ, Indo-Pacific

- Global monthly statistics (area-weighted)
  - Mean Δ = 0.2 W m^{-2}
  - RMSD = 10.6 W m^{-2}
  - Correlation r = 0.99



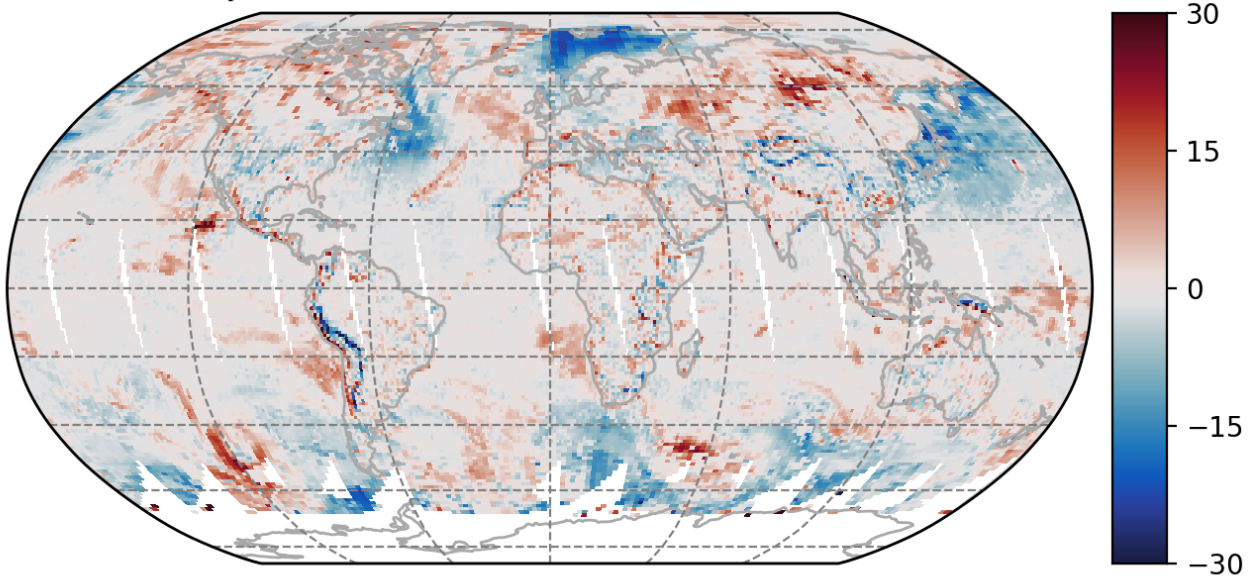
LW↓ diff. (Δ) daily geographic variability ←

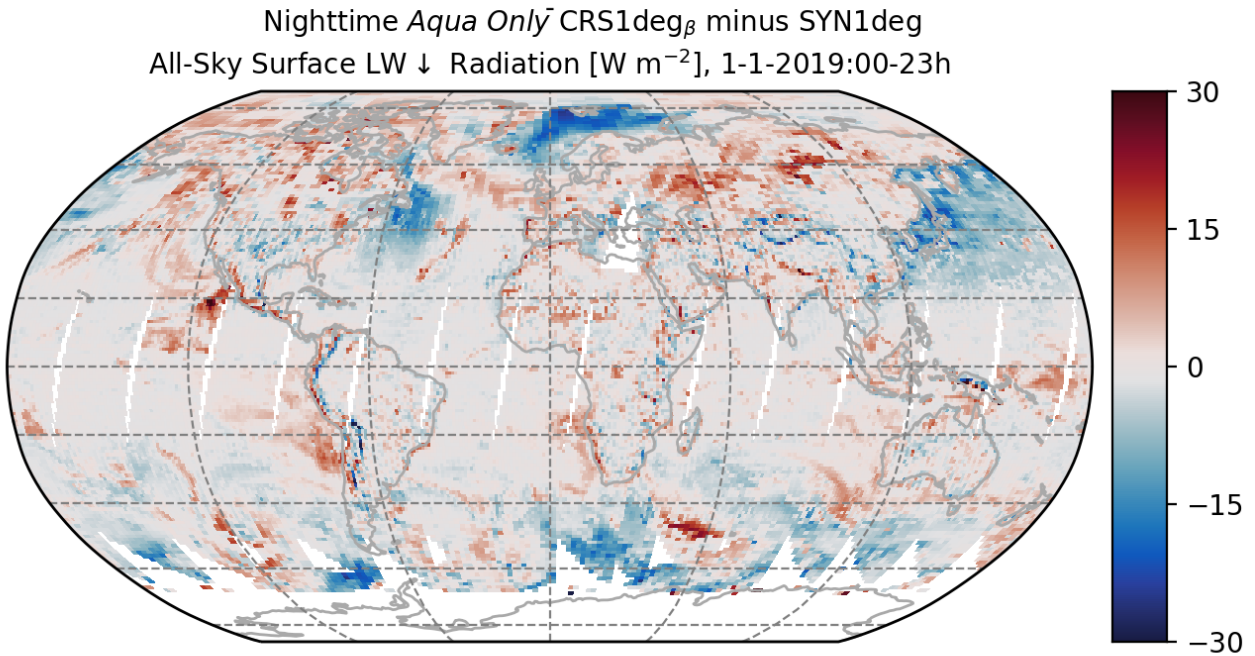


Monthly statistics JAN 2019 ←

Comparing CRS1deg$_\beta$ and SYN1deg-Hour Ed4A Instantaneous Surface LW Fluxes

- CERES SARB/TISA groups perform similar calculations in SYN1deg-Hour
  - Level 3 gridded hourly product
  - Fu-Liou model computed fluxes
  - Has been more rigorously developed and validated
- We also evaluate CRS fluxes against SYN1deg calculations
  1. Average CRS FOVs to 1°x1° CERES nested grid to produce gridded "CRS1deg$_\beta$-Hour" product
  2. Isolate grid boxes observed by Terra or Aqua only (no GEO) & evaluate instantaneous flux Δ
- Good LW↓ agreement over tropical oceans, CRS fluxes lower over mid-latitude oceans
- Weaker cloud signatures at the surface as previously seen in OLR comparison

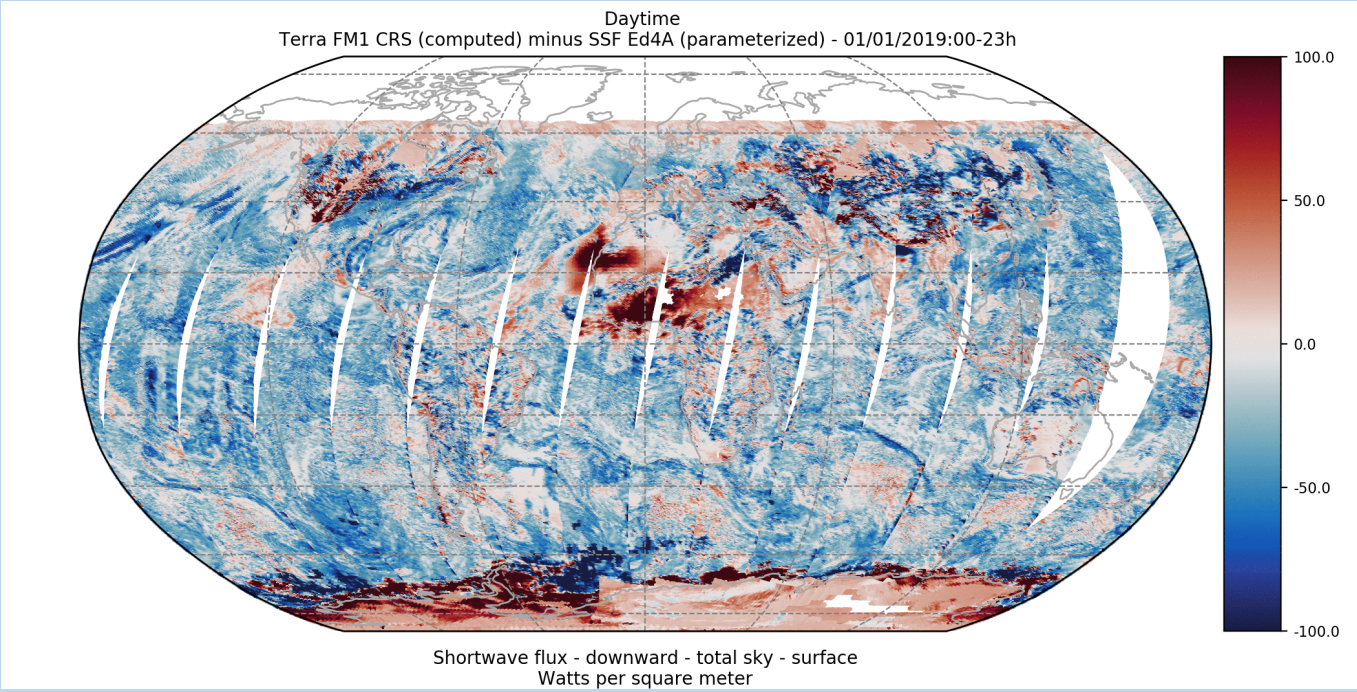




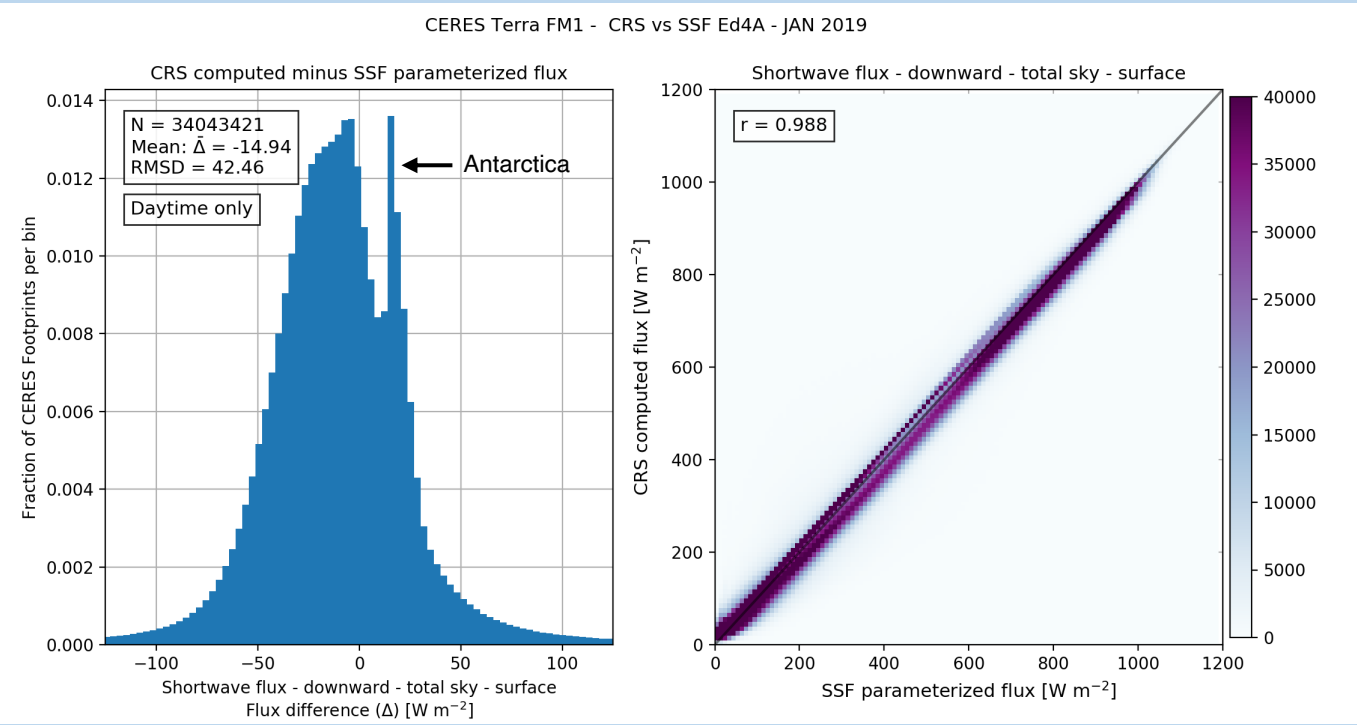
Comparing CRS and "Model B" Parameterized Surface Fluxes (SSF Ed4A)

- SW↓ differences highly variable in time and space
  - particularly over continents
- CRS produces a drastic increase in SW↓ flux over the Antarctic
- Over most of the ocean, CRS SW↓ is considerably smaller than Model B
- Aerosol differences sometimes play a role along NW Africa

- Global monthly statistics (area-weighted)
  - Mean Δ = -14.9 W m^{-2}
  - RMSD = 42.5 W m^{-2}
  - Correlation r = 0.99

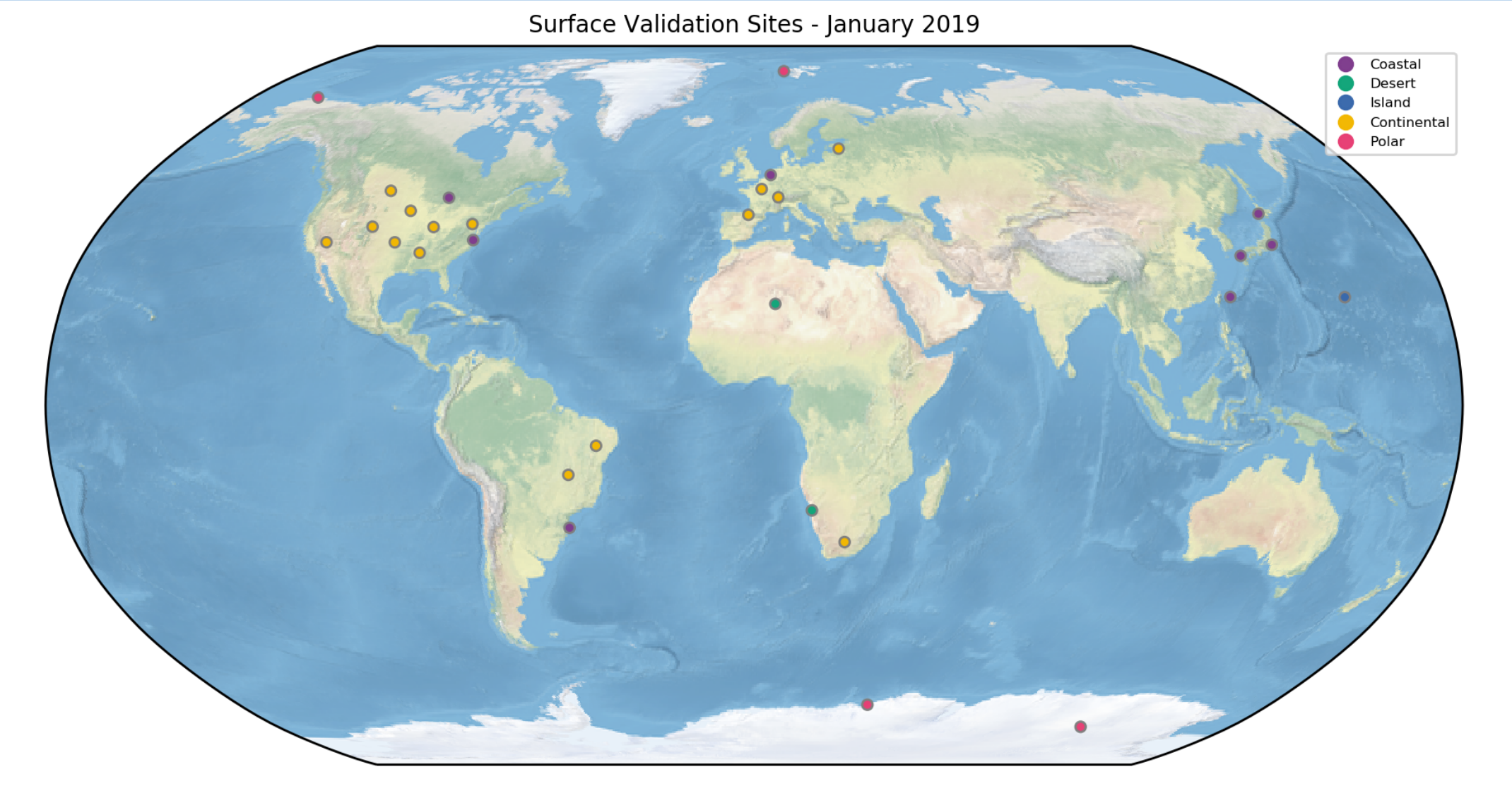


SW↓ diff. (Δ) daily geographic variability



Monthly statistics JAN 2019

CERES Surface Validation Sites



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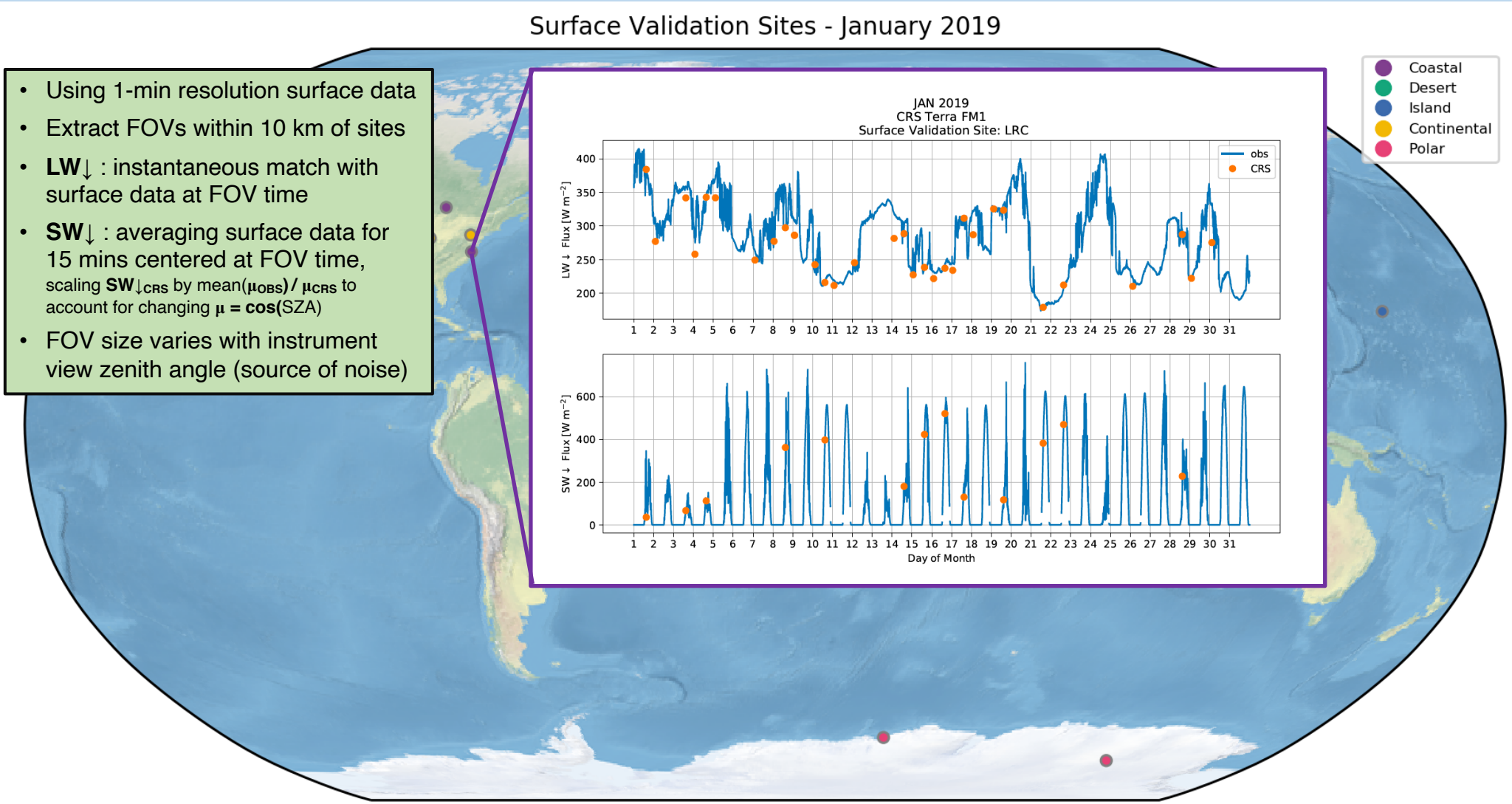
CERES Surface Validation Sites

- Using 1-min resolution surface data
- Extract FOVs within 10 km of sites
- **LW↓** : instantaneous match with surface data at FOV time
- **SW↓** : averaging surface data for 15 mins centered at FOV time, scaling $\mathbf{SW\downarrow_{CRS}}$ by mean(μ_{OBS}) / μ_{CRS} to account for changing μ = **cos**(SZA)
- FOV size varies with instrument view zenith angle (source of noise)



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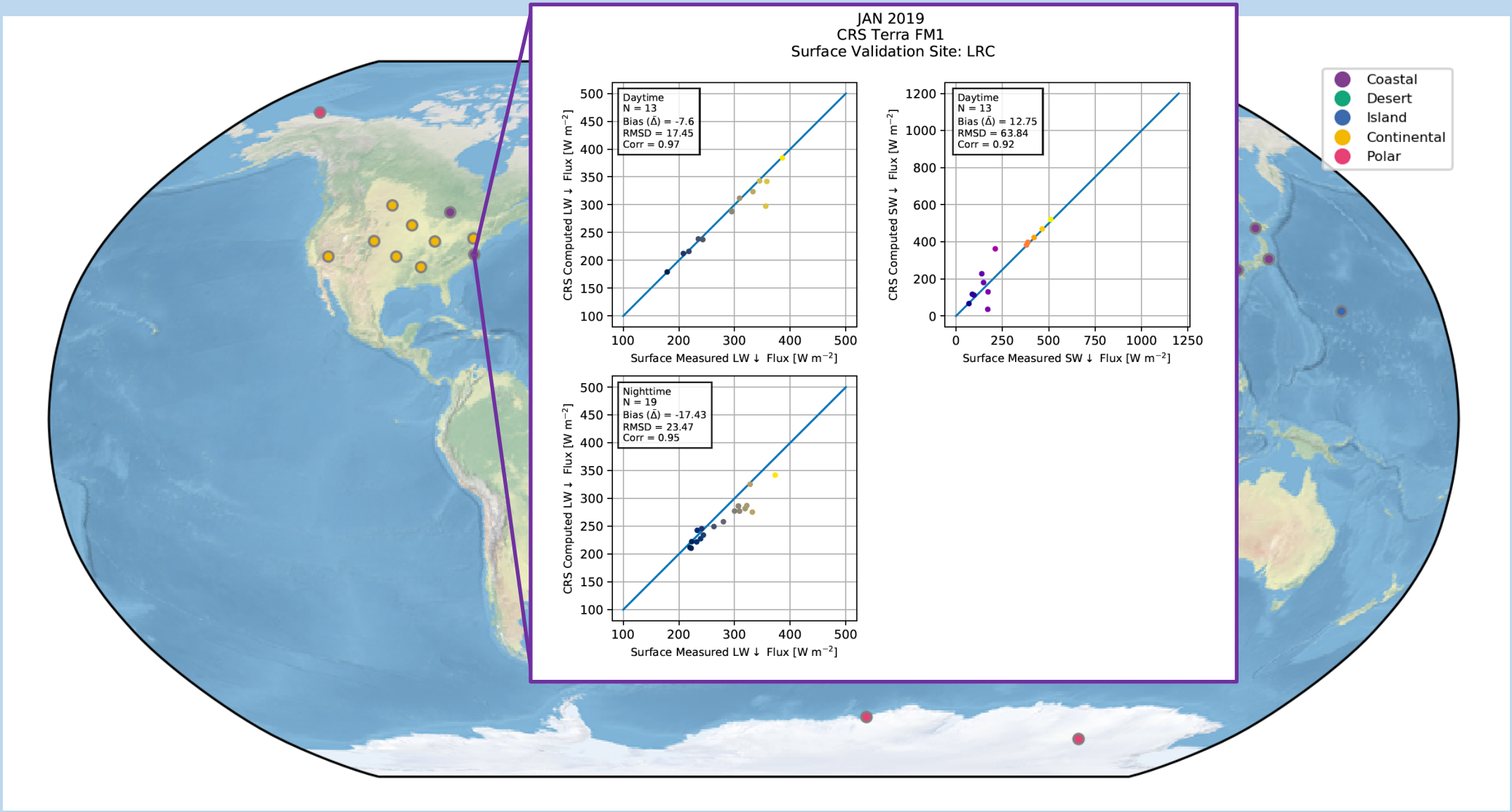
CERES Surface Validation Sites



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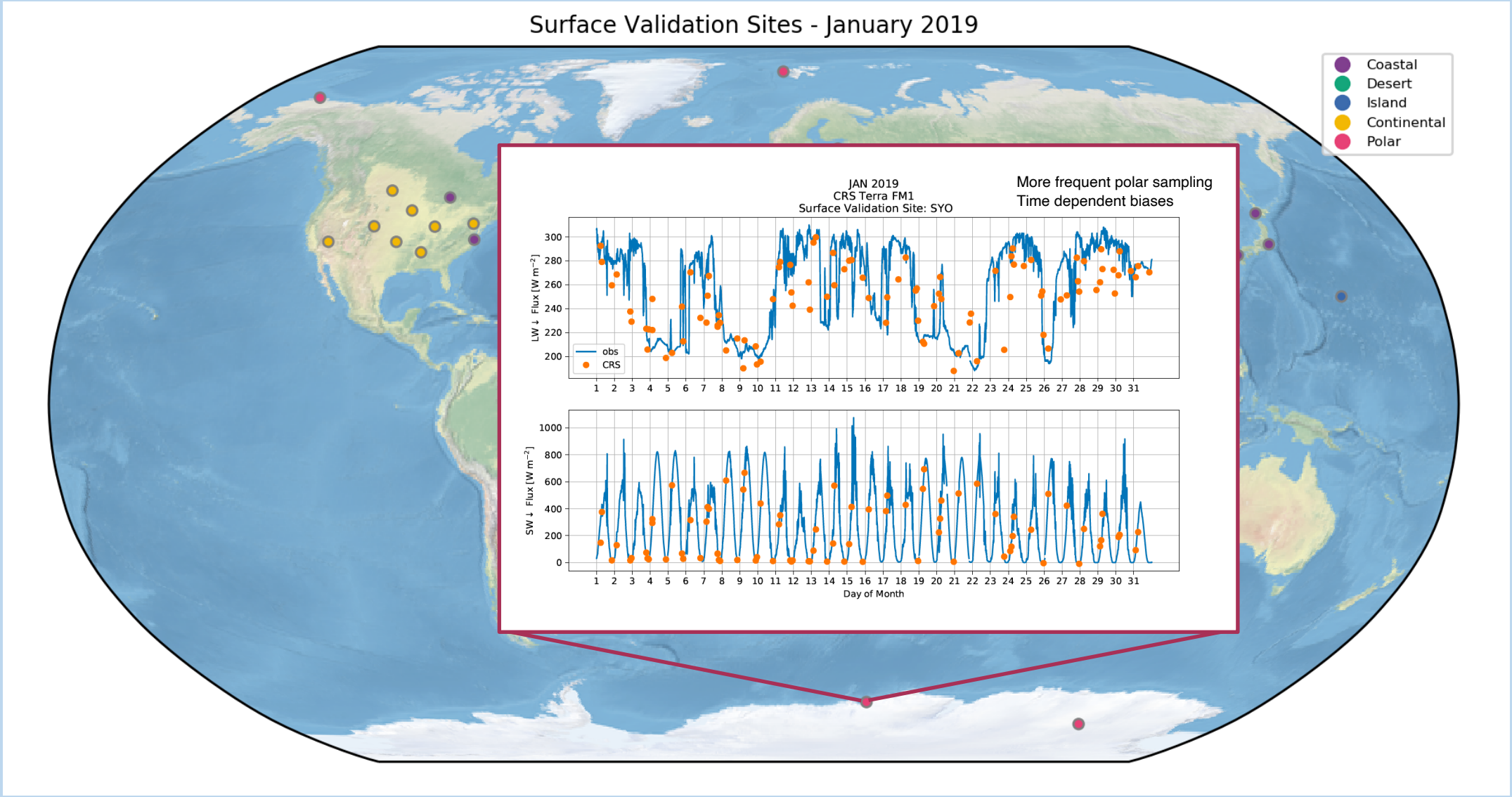
CERES Surface Validation Sites



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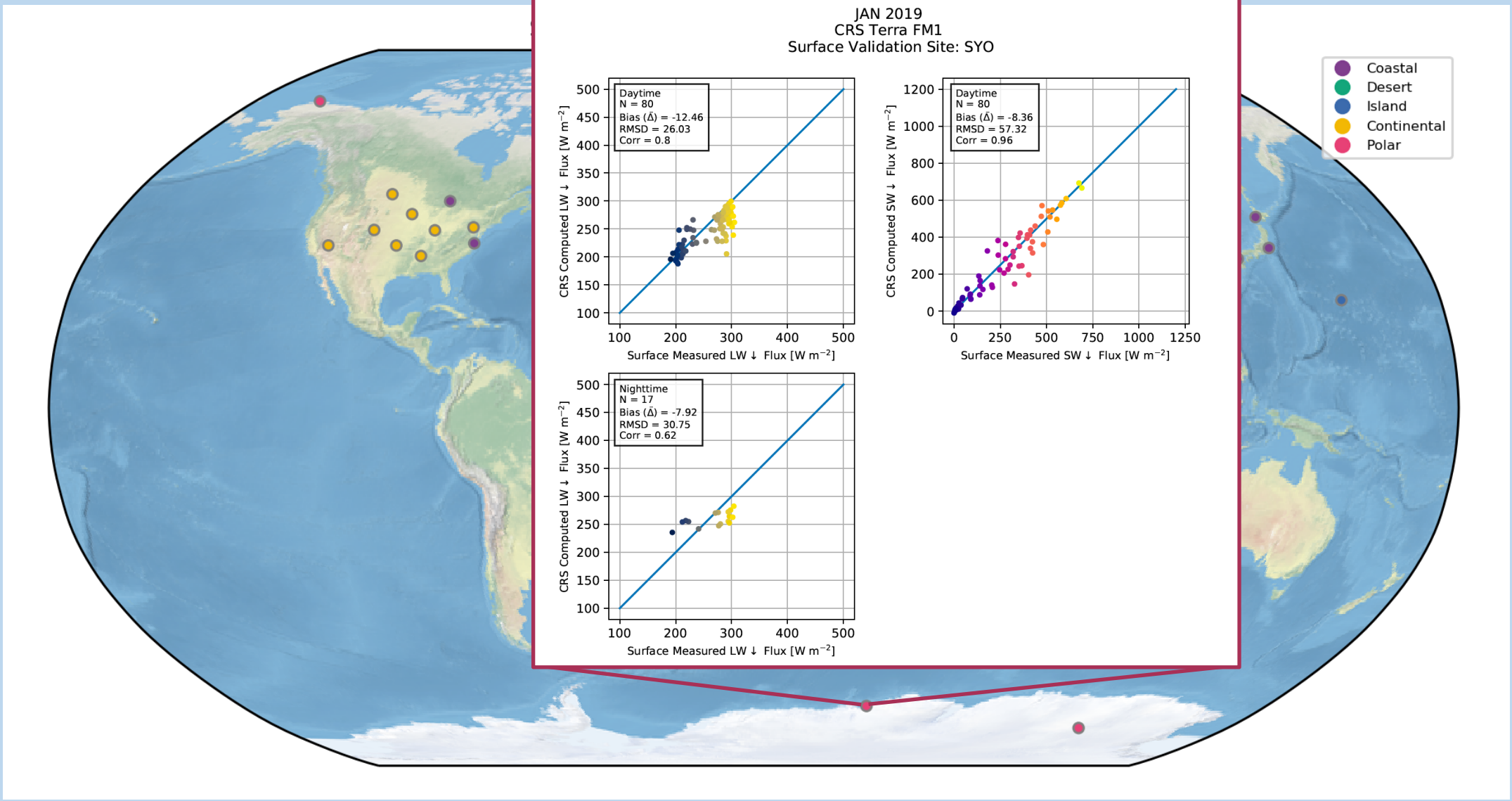
CERES Surface Validation Sites



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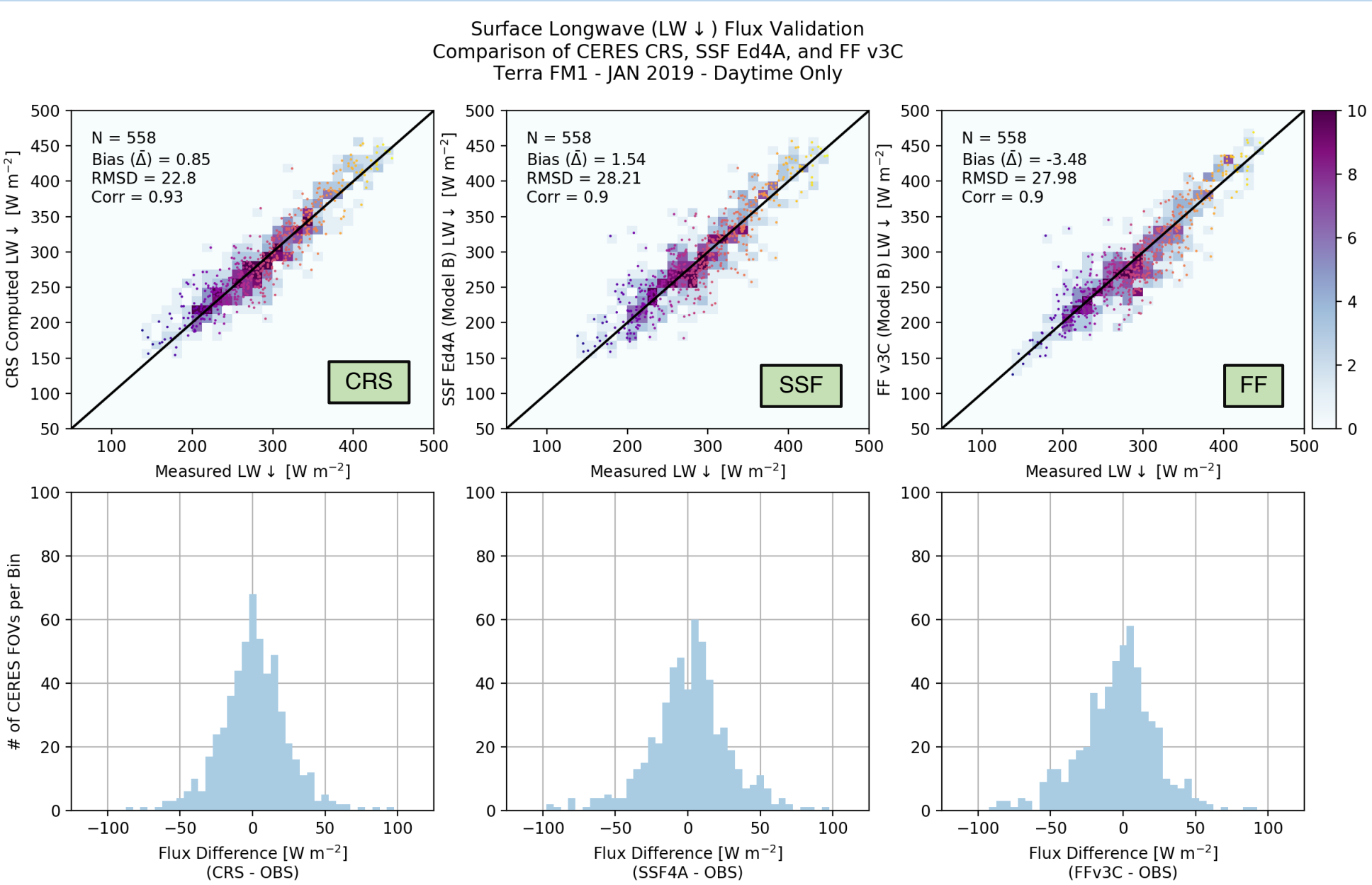

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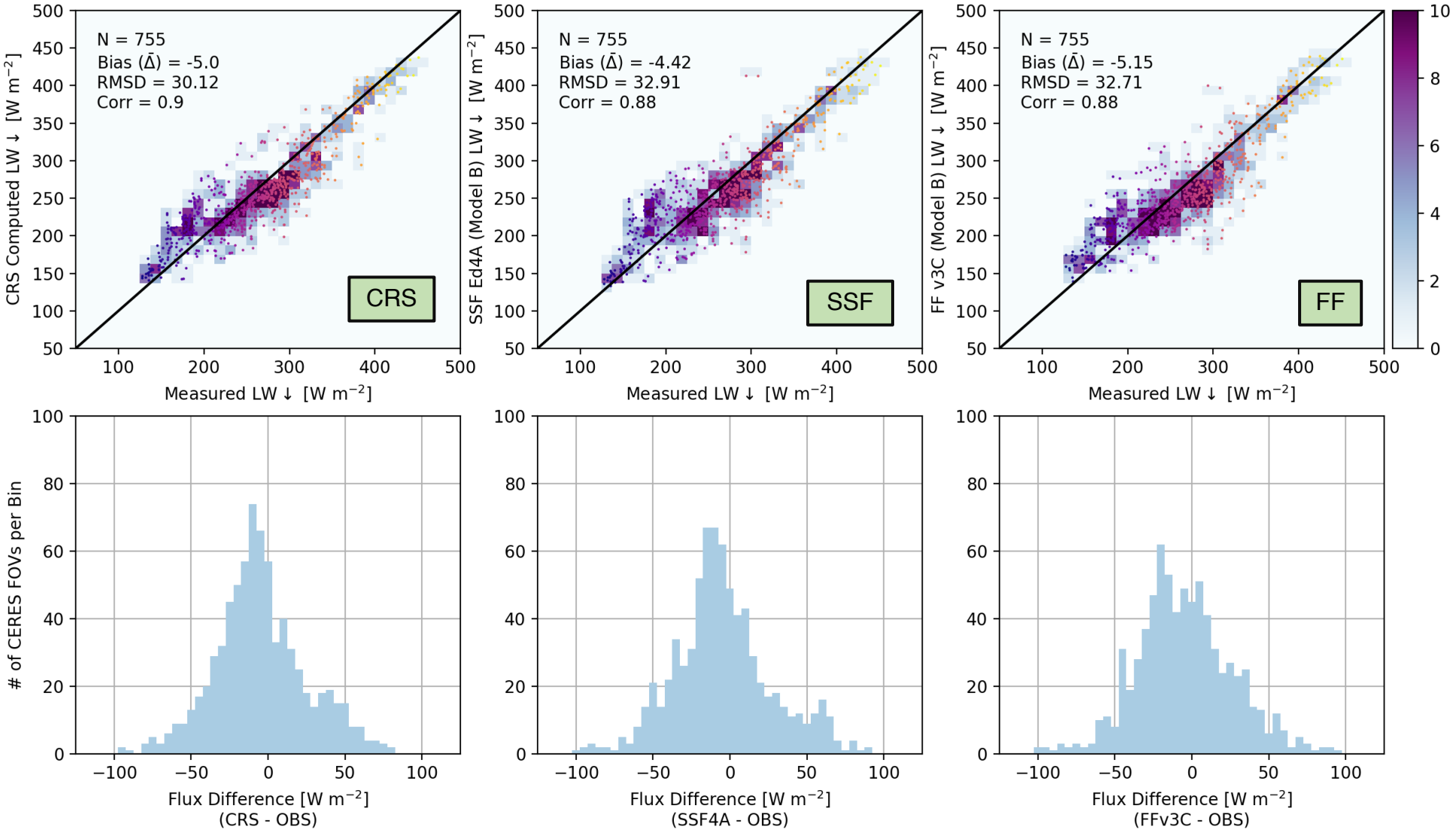
Surface Longwave (LW ↓) Flux Validation
Comparison of CERES CRS, SSF Ed4A, and FF v3C
Terra FM1 - JAN 2019 - Nighttime Only



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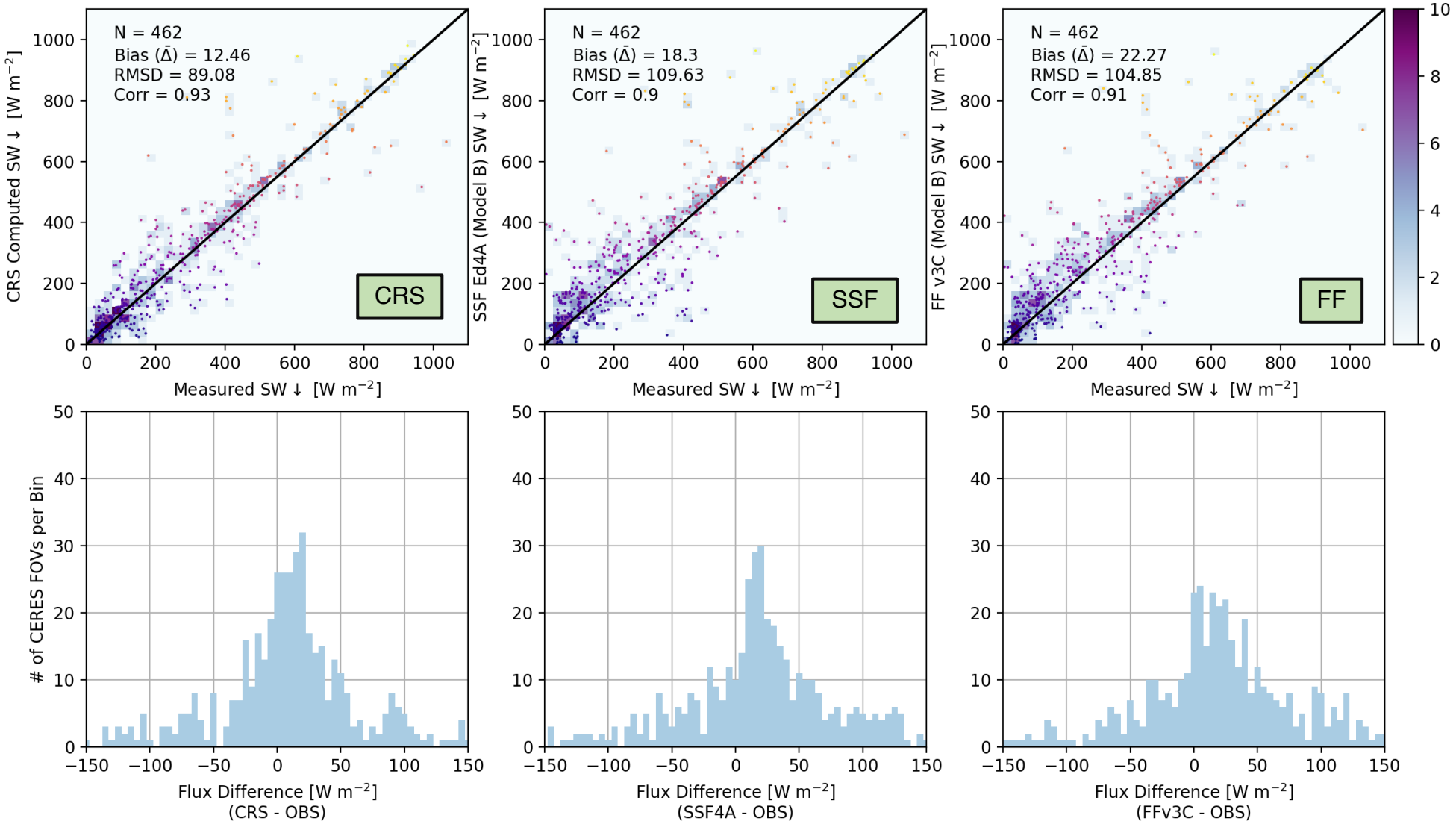
Surface Shortwave (SW ↓) Flux Validation
Comparison of CERES CRS, SSF Ed4A, and FF v3C
Terra FM1 - JAN 2019 - Daytime Only



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Summary & Future Work

- After a decade, the CRS code has been dusted off and is now back under development to extend the SSF product and compute instantaneous footprint-level irradiances via Fu-Liou radiative transfer
  - SW↓↑ and LW↓↑ 6-level broadband flux profiles – all-sky, clear-sky, pristine-sky, & all-sky no aerosol conditions
  - Narrowband fluxes (at surface & TOA), direct + diffuse SW components, PAR, UV, etc.
- Preliminary comparisons show reasonable TOA performance (vs SSF & SYN1deg-Hr Ed4A)
  - Flux biases identified primarily linked to the current treatment of clouds (LW↑, SW↑) and surface albedo (SW↑)
  - Comparisons to observations and other data products are being used to guide further improvements
  - The present framework enables evaluating the radiative impact of changes in CERES cloud retrieval code
- CRS surface fluxes appear slightly improved relative to Model B (SSF Ed4A & FF v3C)
  - Validation using surface radiation measurements from D. Rutan's CAVE
  - CRS LW↓ & SW↓ – smaller bias and RMSD; stronger correlation with observations
- We will be expanding the current analysis to a longer portion of the CERES record & continue efforts to evaluate and remedy any biases prior to release – target release with Ed5
- Potential use of diurnal models to create CRS1deg product for trends free of geostationary artifacts
- These efforts open the door for CRS to supersede SOFA in future L3 CERES products
- Thank you! Questions?

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Extra Slides

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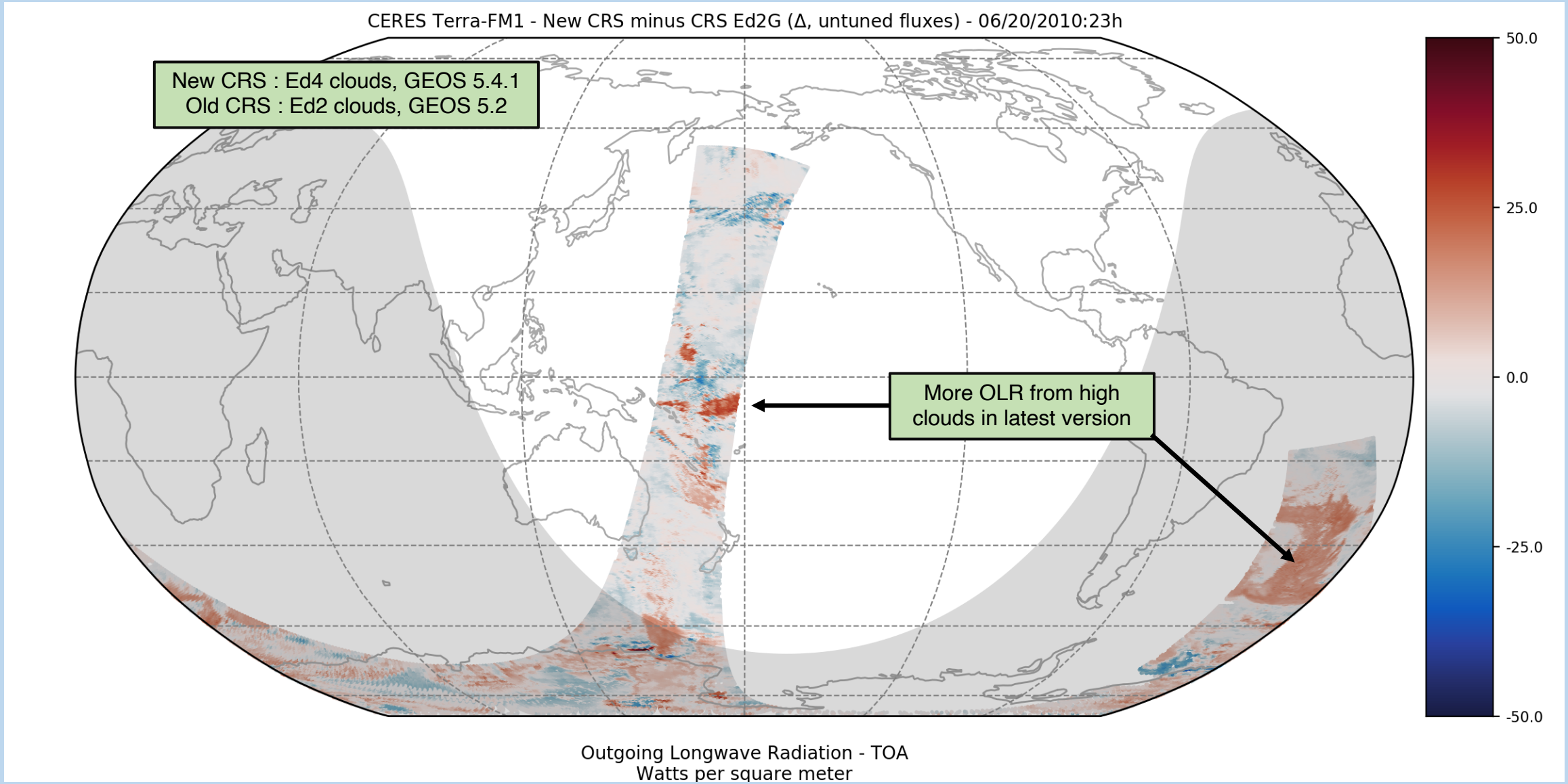
How Does the Latest CRS Compare to the Previous CRS Ed2G?



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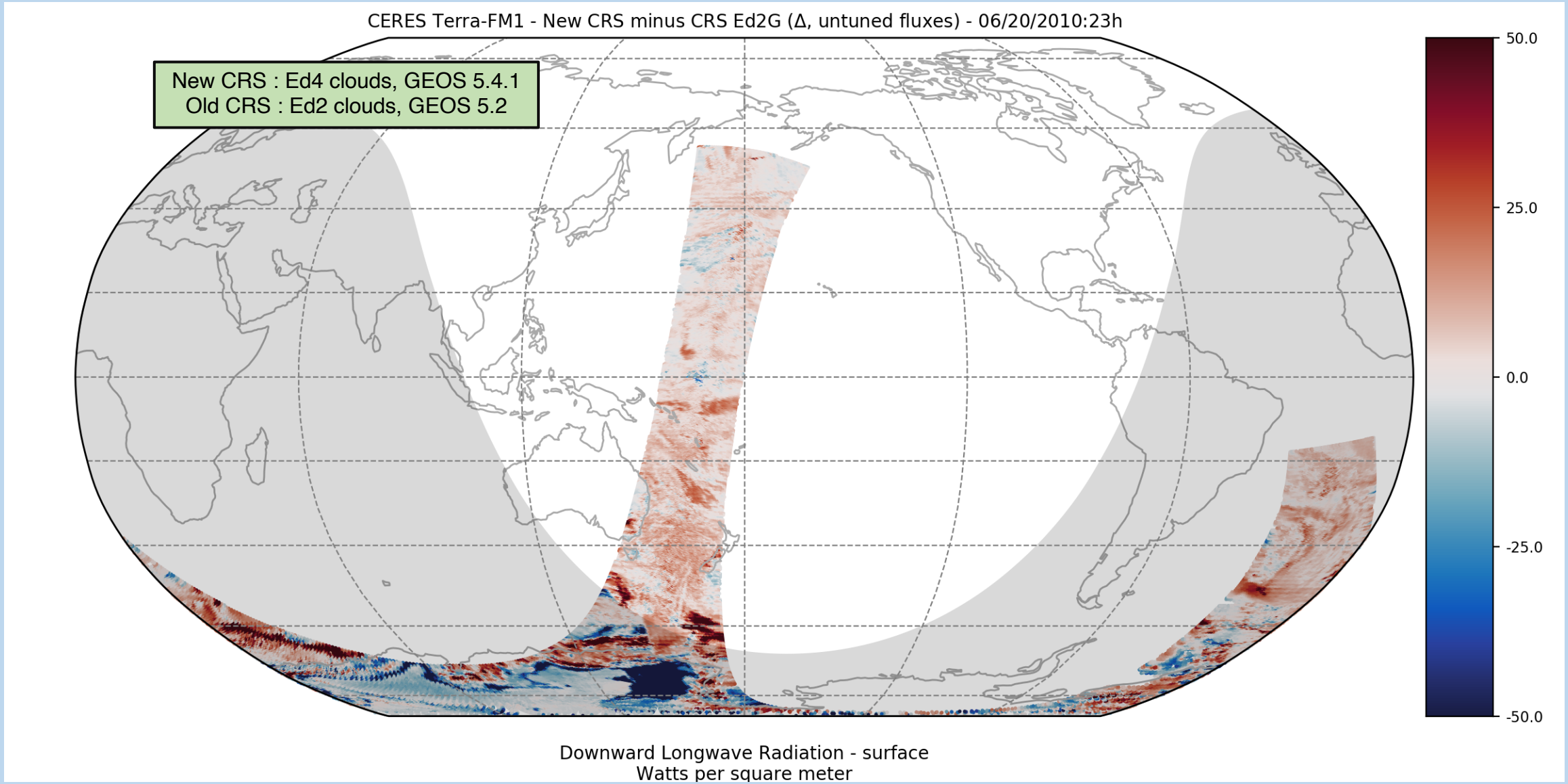

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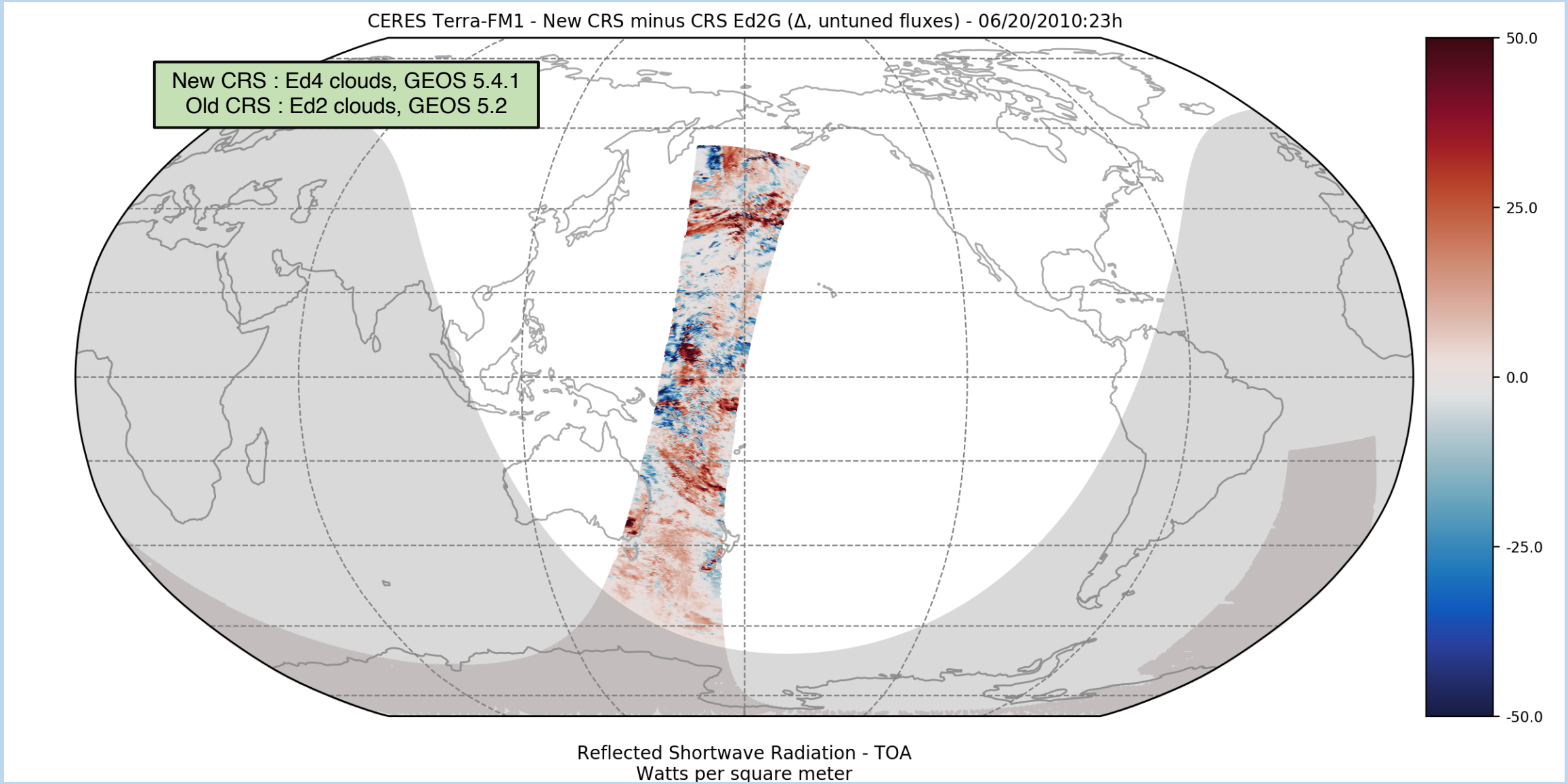

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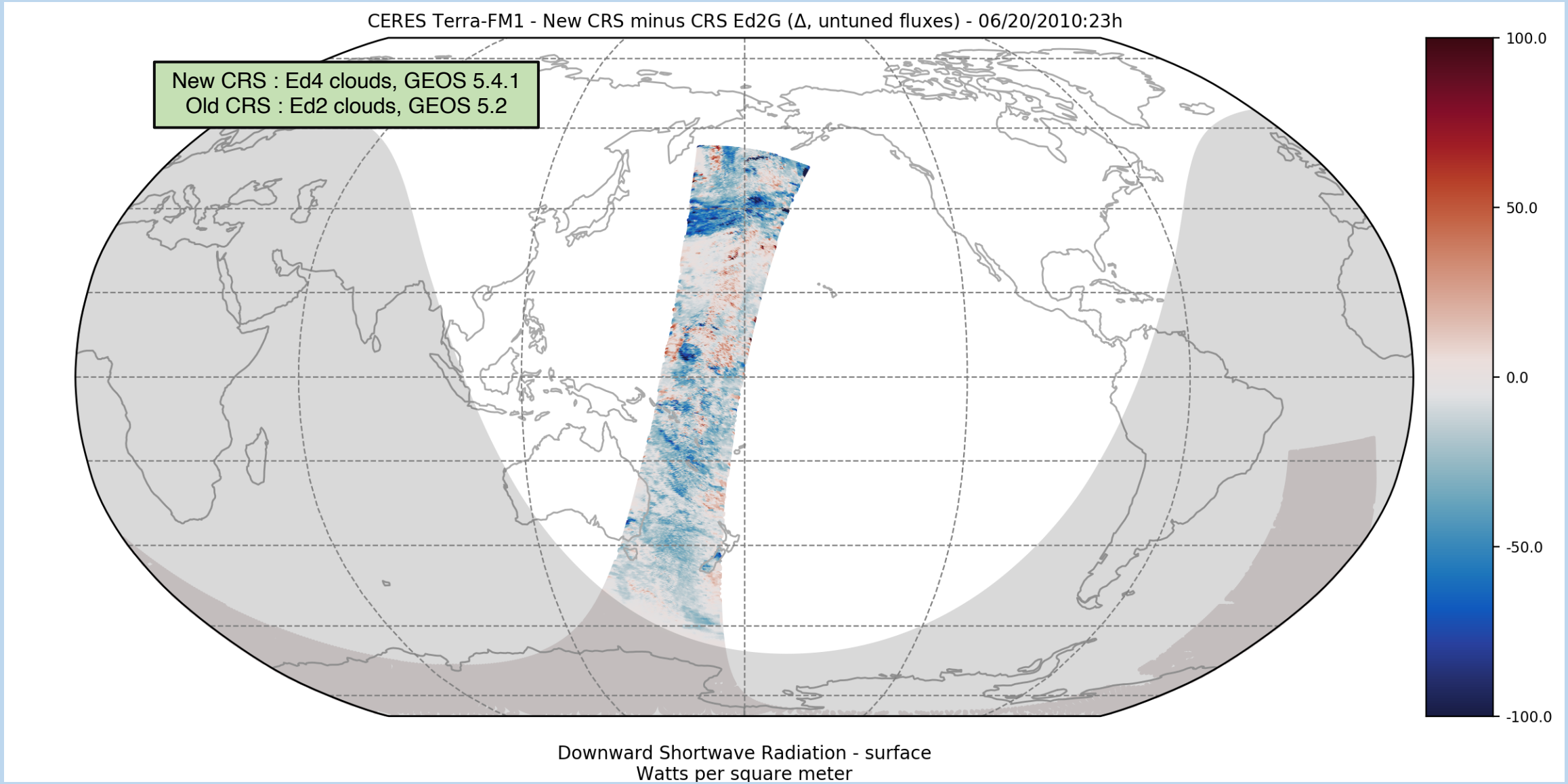

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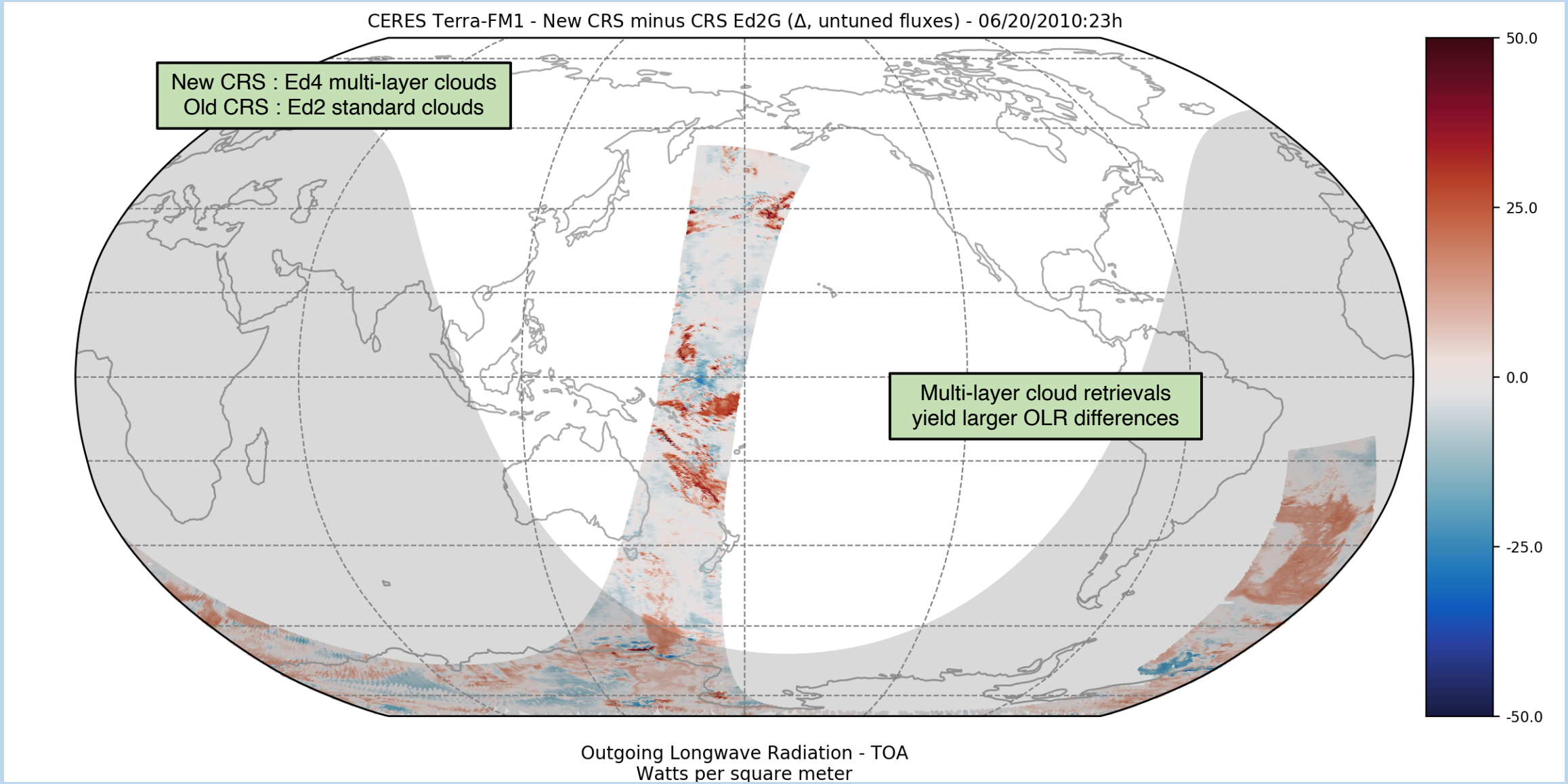

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